2004年12月スマトラ島沖地震津波災害の全体像の解明

河田, 惠昭

2004年スマトラ島沖地震津波災害の全体像の解明
Comprehensive analysis of the damage and its impact on coastal zones by the 2004 Indian Ocean tsunami disaster

（研究課題番号　16800055）

平成 16 年度科学研究費補助金
（特別研究促進費）研究成果報告書
Grant-in-Aid for Special Purposes
Research Report

平成１７年６月
June, 2005

研究代表者
京都大学防災研究所
河田　惠昭

Research Project Leader Yoshiaki KAWATA
Disaster Prevention Research Institute, Kyoto University

2004年スマトラ島沖地震津波災害の全体像の解明
Comprehensive analysis of the damage and its impact on coastal zones by the 2004 Indian Ocean tsunami disaster

（研究課題番号　16800055）

平成16年度科学研究費補助金
（特別研究促進費）研究成果報告書
Grant-in-Aid for Special Purposes
Research Report

平成１７年６月
June, 2005

研究代表者
京都大学防災研究所
河田　惠昭

Research Project Leader Yoshiaki KAWATA
Disaster Prevention Research Institute, Kyoto University

研究組織

研究代表者　：河田　惠昭（京都大学・防災研究所・教授）

研究分担者　：都司　嘉宣（東京大学・地震研究所・助教授）
杉本　良男（人間文化研究機構・国立民族学博物館・教授）
林　　春男（京都大学・防災研究所・教授）
松富　英夫（秋田大学・工学資源学部・助教授）
岡村　行信（産業技術総合研究所・活断層研究センター・海溝型地震履歴研究チーム長）
林　　勲男（人間文化研究機構・国立民族学博物館・助教授）
茅根　　創（東京大学・大学院理学系研究科・助教授）
谷岡勇市郎（北海道大学・大学院理学研究科・助教授）
藤間　功司（防衛大学校・建設環境工学科・教授）
今村　文彦（東北大学・大学院工学研究科・教授）
松山　昌史（(財）電力中央研究所・地球工学研究所・主任研究員）
高橋　智幸（秋田大学・工学資源学部・助教授）
牧　　紀男（(独）防災科学技術研究所・地震防災フロンティア研究センター・チームリーダー）
越村　俊一（(財）阪神・淡路大震災記念協会　人と防災未来センター・専任研究員）

研究協力者　：安田　誠宏（京都大学・防災研究所・助手）
鎌滝　孝信（産業技術総合研究所・活断層研究センター・特別研究員）
鳴原　良典（防衛大学校・建設環境工学科・助手）
西村　裕一（北海道大学・大学院理学研究科・助所）
堀江　　啓（(独）防災科学技術研究所・地震防災フロンティア研究センター・災害過程シミュレーションチーム研究員）
西　　芳実（東京大学・総合文化研究科・教務補佐員）
山本　博之（人間文化研究機構・国立民族学博物館・教授）
深尾　淳一（拓殖大学・政経学部・非常勤講師）
杉本　星子（京都文教大学・文化人類学部・教授）
高桑　史子（東京都立短期大学・文化国際学科・教授）

交付決定額（配分額）　（単位：千円）

	直接経費	間接経費	合　計
平成16年度	14,500	0	14,500
総　計	14,500	0	14,500

研究発表

（1） 学会誌等

松冨英夫・榊山　勉・Sindhu Nugroho・都司嘉宣・谷岡勇市郎・西村裕一・鎌滝孝信・村上嘉謙・松山昌史・栗塚一範，Banda Aceh と周辺における 2004 年インド洋津波と被害想定からみた課題，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

松冨英夫・高橋智幸・松山昌史・原田賢治・平石哲也・Seree Supartid・Sittichai Naksuksakul タイの Khao Lak と Phuket 島における 2004 年スマトラ島沖津波とその被害，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

藤間功司・鴫原良典・富田孝史・本多和彦・信岡尚道・越村俊一・藤井裕之・半沢稔・辰巳正弘・折下定夫・大谷英夫，モルディブにおけるインド洋津波の現地調査，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

大谷英夫・藤間功司・鴫原良典・富田孝史・本多和彦・信岡尚道・越村俊一・折下定夫・辰巳正弘・半沢稔・藤井裕之，インド洋大津波によるモルディブ共和国マレ島・空港島の浸水特性とそれに及ぼす護岸・離岸堤の影響，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

松山昌史，2004 スマトラ沖地震津波の数値解析，2004 年 12 月 26 日スマトラ島沖地震報告会　梗概集，pp.75-80，2005.

松山昌史，インド洋大津波（スマトラ沖地震）の教訓，月刊エネルギ−，3 月号，2005.

平石哲也，インド洋地震津波の被害例について−タイにおける事例を中心として−，港湾空港技術研究所資料，20p.，2005.

安田誠宏，原田賢治，2004 年 12 月 26 日スマトラ沖地震津波災害，自然災害科学，Vol.23，No.4，pp. 603−615，2005.

鈴鹿陽・高橋智幸・松冨英夫，タイ南西部に来襲したスマトラ島沖地震津波の数値解析，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

鈴木由美・児島正一郎・高橋智幸・高橋心平，人工衛星画像を用いた津波の発生および伝播観測に関する検討，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

越村俊一・高島正典・鈴木進吾・林春男・今村文彦・河田惠昭，インド洋における巨大地震津波災害ポテンシャルの評価，土木学会海岸工学論文集，第 52 巻，2005（印刷中）．

山本博之，一本の旗−アチェからのメッセージ，月刊みんぱく，30（6），14p.，2005.

西　芳美，外来者との繋がりが保証する自立性：アチェ近現代史をふりかえる，JAMS News，31, pp.22-27，2005.

西　芳美，救援者と被災者を結ぶ経路を確保する：スマトラ沖地震・津波の救援復興活動から，JAMS News，32, pp.36-40，2005.

(2)　口頭発表　なし

(3)　出版物　　なし

研究成果による工業所得権の出願・取得状況

なし

Investigators

- Yoshiaki Kawata, Disaster Prevention Research Institute, Kyoto University, Professor
- Yoshinobu Tsuji, Earthquake Research Institute, University of Tokyo, Associate Professor
- Yoshio Sugimoto, National Museum of Ethnology, Professor
- Haruo Hayashi, Disaster Prevention Research Institute, Kyoto University, Professor
- Hideo Matsutomi, Faculty of Engineering and Resource Science, Akita University, Professor
- Yukinobu Okamura, Subduction-zone Earthquake Recurrence Research Team, Active Fault Research Center, National Institute of Advanced Industrial Science and Technology, Leader
- Isao Hayashi, National Museum of Ethnology, Associate Professor
- Hajime Kayane, Department of Earth and Planetary Science, University of Tokyo, Associate Professor
- Yuichiro Tanioka , Institute of Seismology and Volcanology, University, Associate Professor
- Koji Fujima , Department of Civil and Environmental Engineering, National Defense Academy of Japan, Professor
- Fumihiko Imamura, School of Engineering, Tohoku University, Professor
- Masafumi Matsuyama, Fluid Dynamics Sector, Central Research Institute of Electric Power Industry, Research Engineer
- Tomoyuki Takahashi, Faculty of Engineering and Resource Science, Akita University, Associate Professor
- Norio Maki, Disaster Process Simulation Team, Earthquake Disaster Mitigation Research Center, Team Leader
- Shunichi Koshimura, Disaster Reduction and Human Renovation Inst., Researcher

Co-operative Researchers

- Tomohiro Yasuda, Disaster Prevention Research Institute, Kyoto University, Research Associate
- Yoshinori Shigihara, Department of Civil and Environmental Engineering, National Defense Academy of Japan, Research Associate
- Yuichi Nishimura, Institute of Seismology and Volcanology, University, Research Associate
- Kei Horie, Disaster Process Simulation Team, Earthquake Disaster Mitigation Research Center, Researcher
- Yoshimi Nishi, Graduate School of Arts and Sciences, University of Tokyo
- Hiroyuki Yamamoto, National Museum of Ethnology, Associate Professor
- Junichi Fukao, Faculty of Political Science and Economics, Takushoku University, Lecturer
- Sugimoto Seiko, Faculty of Ethnology. Kyoto Bunkyo University, Professor
- Fumiko Takakuwa , Tokyo Metropolitan College, Professor

Contents

Preface

The 9.0 Sumatra-Andaman earthquake was an undersea earthquake that occurred at 00:58:53 UTC (07:58:53 local time) on December 26, 2004. As a typical reverse fault earthquake along a plate boundary, the earthquake generated a megatsunami that was among the deadliest disasters in modern history, killing over 200,000 people. Therefore, we call this disaster as the 2004 Indian Ocean tsunami. Various values were given for the magnitude of the earthquake, initially reported as 8.1 by the USGS and recently ranging from 9.0 to 9.3. This difference was due to lack of accurate and seismic wave records at near the seismic zone as well as long rapture time of nearly ten minutes. The earthquake originated in the Indian Ocean just north of Simeulue island, off the western coast of northern Sumatra, Indonesia. The hypocenter of the main earthquake was at 3.316'N, 95.854'E, some 160km west of Sumatra, at the depth of 30km (initially reported as 10km) below MSL. This is the extreme western end of the Ring of Fire. The India Plate is part of the great Indo-Australian Plate, which underlies the Indian Ocean and Bay of Bengal, and drifting northeast at an average of 6 cm/year. The India Plate meets the Eurasian Plate at the Sunda trench. As well as the sideways movement between the plates, the sea bed is estimated to have risen by several meters, displacing an estimated 30 km^3 of water and triggering devastating tsunami waves. The total energy released by the earthquake in the Indian Ocean has been estimated as 4.3×10^{18} joules. This is equivalent to 100 gigatons of TNT. There was 10m movement laterally and 4 to 5 m vertically along the fault line. In the south-north direction of the seismic zone, we have three segments (south, middle and north) which generated last earthquake in 1861, 1881 and 1941 with the magnitude of near or more than 8 respectively. In this time Three segments moved simultaneously..

The resulting tsunami devastated the shores of Indonesia, Sri Lanka, India, Thailand, the Maldives and other countries with waves up to 48.9m. The westward propagated tsunamis were offensive (surging) waves and hit Sri Lanka and India, and the eastward ones were defensive (recession) waves and invaded Indonesia and Thailand. It caused serious damage and deaths as far as the east coast of Africa. Because the 1,200 km of fault line affected by the quake was in a nearly north-south orientation, the greatest strength of the tsunami waves was in an east-west direction. Bangladesh, which lies at the northern end of Bay of Bengal, had very few casualties despite beimg a low-lying country relatively near the epicenter. It also benefited from the fact that the earthquake proceeded more slowly in the northern rupture zone, greatly reducing the energy of the western coast of India, and the western coast of Sri Lanka also suffered substantial impacts. If the north segment generates normal (not slow rupture) earthquake, estimated tsunami height at Bangladesh will be more than 5 to 6m and kill more than one million people. Because of the distances involved, the tsunami took anywhere from fifteen minutes to seven hours (for Somalia) to reach the various coastlines.

The reported death toll from the earthquake, the tsunami and the resultant floods varies widely because of confusion and conflicting reports, but could total to over 265,000 people with tens of thousands reported missing, and over a million left homeless. Last ten years, urbanization has developed in Asian developing countries and especially, so many people live in close to coastal area in which flooding due to heavy rainfall, storm surges and tsunamis are very popular. Some relief agencies report that one-third of the dead appear to be children. This is a result of the high proportion of children in the population of many of the affected regions and because children were the least able to resist being overcome by the surging waters. Oxfam went on to report that as many as four times more women than men were killed in some regions because they were waiting on the beach for the fishermen to return and looking after their children in the houses. In addition to the large number of local residents, up to 9,000 foreign tourists enjoying the peak holiday travel season were among the dead or missing, especially, Scandinavians. We lost 36 Japanese people (24 in Thailand and 12 in Sri Lanka).

From 200,000 to 300,000 people are thought to have died as a result of the tsunami, and the count is not yet complete. The true death toll may never be known due to bodies having been swept out to sea. To reduce human casualty, it is necessary to prepare integrated tsunami reduction systems including a tsunami warning system for the Indian Ocean. An effective tsunami warning systems in the Pacific Ocean was established after the 1960 Chilean Tsunami and 26 countries located in the "Ring of Fire" support financially under UNESCO activities.

We have just started learning the lessons from the Indian Ocean Tsunami Disaster. As the first step, we tried to comprehend the impacts of tsunami disaster along the coastal zone of Indian Ocean, focusing on the following matters.

1) Surveying tsunami impacts on coastal zones

1-1) Comprehensive analysis of the damage by the Indian Ocean tsunami disaster

We surveyed the tsunami impact on coastal zones, building GIS database of extent of inundation zone, damage on structures, local tsunami height, and current velocities, through the analysis of various data, such as, satellite imageries, videos and photos taken by survivors, and numerical model results.

1-2) Post tsunami field survey

We deployed the post tsunami survey team to investigate the damage, measure the extent of tsunami inundation zone, local tsunami run-up, and current velocities, and to collect eyewitness accounts.

2) Ethnological study to illustrate the cause of extensive tsunami casualties

Using the ethnological approach, we attempt to illustrate the cause of extensive tsunami casualties and missing that have been counted more than 200,000 in the entire Indian Ocean, through the interviews from survivors, tourists, coastal residents, emergency management officials, and employees of resort facilities

In the following chapter, we report our survey results and analysis. In Chapter 1, we describe an overview of the Indian Ocean tsunami and seismic/ tectonic setting in the Indian Ocean, including the results of the numerical modeling of trans-oceanic propagation of tsunami. In Chapters 2, 3, 4 and 5, we report the results of post tsunami survey of Indonesia, Sri Lanka, Thailand and Maldives, where the most significant damage were reported. These are mainly focusing on measuring the tsunami height, current velocity, and extent of inundation zone, such as the physical aspects of the Indian Ocean tsunami disaster. Then in

Chapter 6, we report the social impacts of tsunami disaster in Indonesia, Thailand, Sri Lanka, and India, through the field investigation on the emergency response and relief activities. In the last chapter, Chapter 7, we introduce how we comprehended and disseminated lots of information, to develop a sort of "clearinghouse" and database through the internet to share the information and the survey results.

This research and survey results reported here are as the results of the contribution of not only the involved researchers in our projects but also lots of people involved in this tragic disaster. We thank all the people who helped us and contributed to achieve our research objectives. Also we hope this report will help to reduce the loss and damage of tsunami disaster in the future. This research is financially supported by the ministry of education, culture, sports and technology of Japan.

Chapter 1 The 2004 December, Northern Sumatra Earthquake and the Indian Ocean Tsunamis

1.1 An Overview

On December 26, 2004, 00:58 (UTC), 07:58 (Local Time, Indonesia), a great earthquake occurred off the west coast of northern Sumatra, Indonesia. The magnitude of this earthquake was 9.0 and this was the fourth largest earthquake in the world since 1900. The earthquake occurred on the plate boundary that India plate subducts beneath the overriding Burma plate. Fig. 1.1 shows the tectonic setting of the northern Indian Ocean [(1)]. The main shock occurred off the west coast of Sumatra Island and the aftershocks extended to the northward as long as approximately 1,000 km long of rupture zone.

The tsunami accompanied with this earthquake propagated in the entire Indian Ocean and caused extensive and significant damage. The reported number of casualties are approximately 300,000 (230,000 killed in Indonesia by the earthquake and tsunami, at least more than 29,000 killed in Sri Lanka, more than 10,000 in India, more than 5,000 in Thailand, and 82 killed in Maldives by tsunamis) and more than 22,000 are still missing.

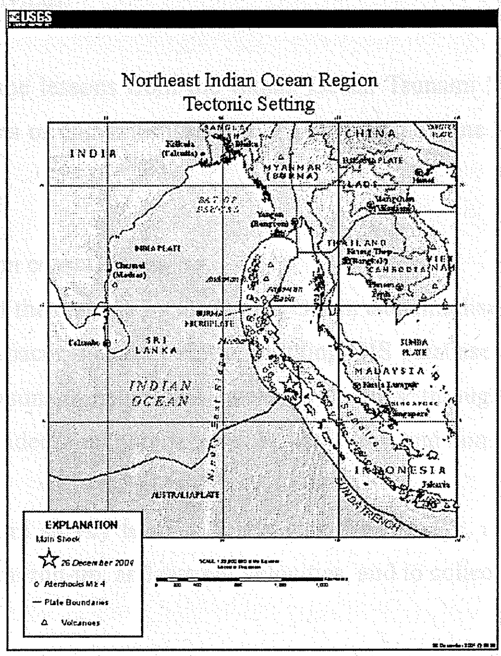


Fig. 1.1 Tectonic setting of the Indian Ocean (USGS)

Fig. 1.2 shows the estimated tsunami travel time in the Indian Ocean [(2)]. The tsunami attacked the coasts of Thailand and Sri Lanka in 2 hours, Maldives within 4 hours, and east Africa in 10 hours. The tsunami were observed at a great number of tidal stations in the Indian Ocean, and even in Antarctica [(3)]

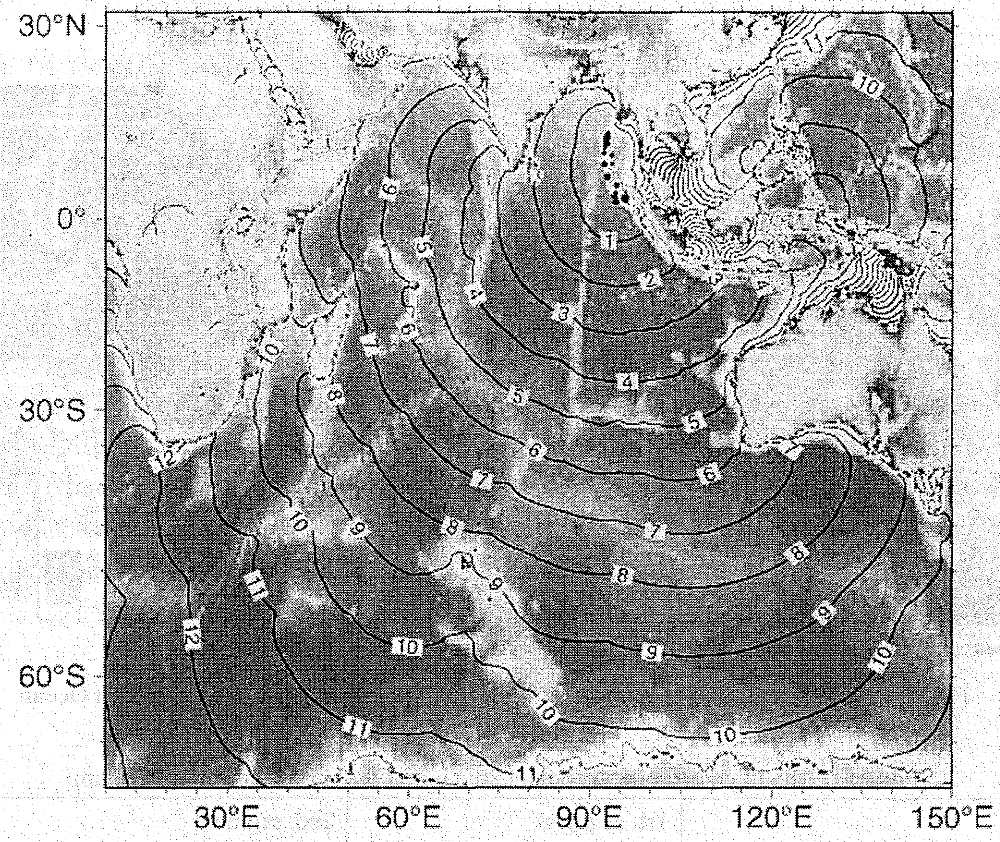


Fig. 1.2 The computed tsunami travel time within the Indian Ocean (Computed and drawn by Kenji Satake, AIST, Japan)

1.2 Numerical Modeling of Tsunami

Focusing on comprehending the tsunami propagation characteristics in the Indian Ocean, the numerical modeling of tsunami is performed by using TUNAMI code developed by Tohoku University, Japan (4). The model is based on the linear shallow water equations of spherical co-ordinate system. Fig. 1.3 shows the computational domain and the sea bottom topography of the Indian Ocean. We use the 2 arc-minute grids of bathymetry of ETOPO2, provided by the National Geophysical Data Center (5)

We assume that the sea bottom deformation due to the earthquake pushes up / draws down the overlying water, forming the initial sea surface of tsunami. Table 2.1 indicates the fault parameters to compute the sea bottom deformation. Strike is the azimuth of the fault plane (fault strike line) measured from North, and dip is the azimuth of the fault plane measured from the horizontal line. Slip is the angle of the fault slip direction measured from the horizontal line. The detailed definitions of the parameters are indicated in the appendix of this chapter. Here, the rupture zone is divided into the two subfaults. We applied the theory of Okada (1985) to obtain the sea bottom deformation (6).

The Indian Ocean
Sea Bottom Topography

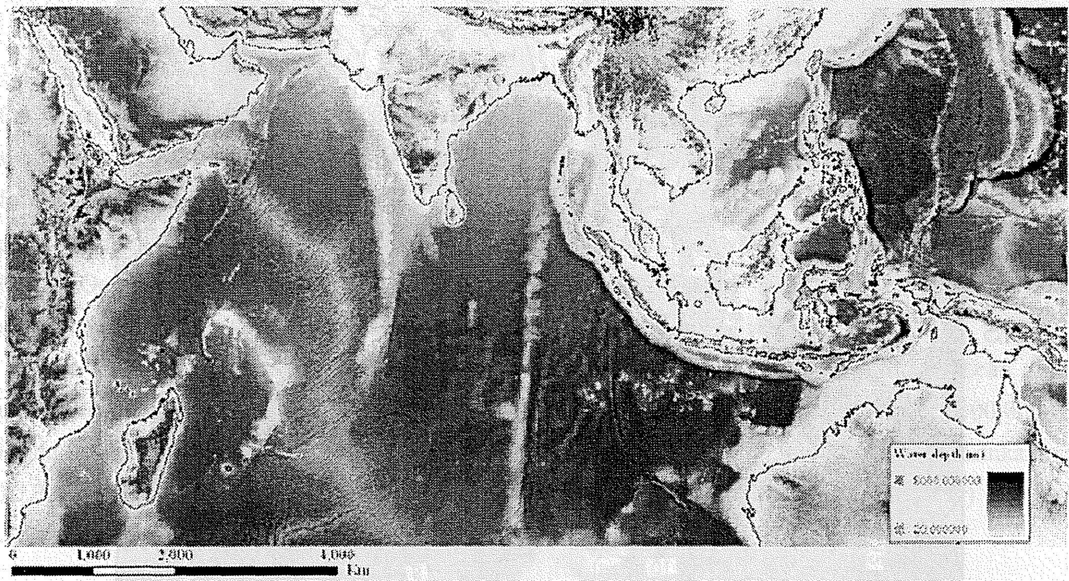


Fig. 1.3 The computational domain and the sea bottom topography of the Indian Ocean

Table 1.1 Fault parameters to compute the initial sea surface profile of tsunami

	1st. segment (southern part)	2nd. segment (northern part)
Strike, Dip, and Slip (degree)	329, 15, and 90	345, 15, and 90
L and W (km)	500 and 150	400 and 150
Dislocation (m)	11 m	11 m
Fault depth (km)	10 km	10 km

The 2004 Indian Ocean Tsunami
Initial Sea Surface Elevation

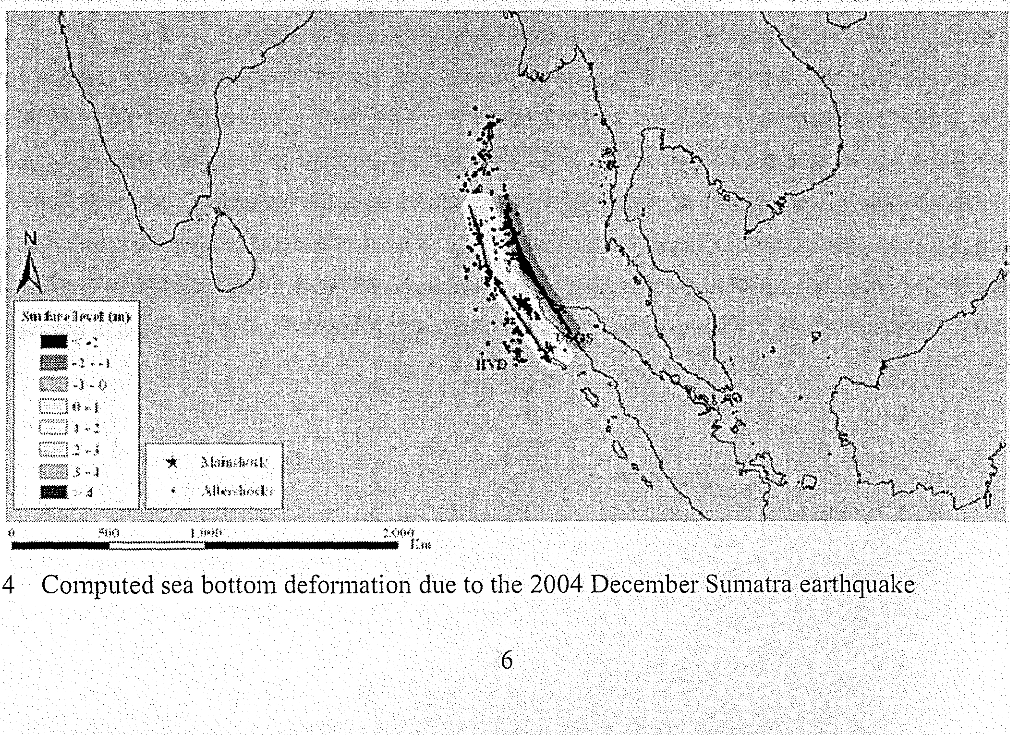


Fig. 1.4 Computed sea bottom deformation due to the 2004 December Sumatra earthquake

Fig. 1.4 shows the computed sea bottom deformation, i.e. the initial sea surface profile of tsunami. The black dots indicate the distribution of aftershocks. The tectonics of this region suggests the thrust fault as the focal mechanism, generating the subsidence of the coast of northern Sumatra Island. The maximum uplift of the sea bottom is computed as 4.7 m , and maximum subsidence as 2.7 m.

Fig. 1.5 shows the snap shots of tsunami propagation 0, 30, 60, 120, 150, 180, and 210 minutes after the earthquake. Also, Fig. 1.6 is the distribution of computed maximum tsunami height in the entire Indian Ocean. The model results show that the tsunami energy was extended to the entire coasts of the Indian Ocean. Especially, significant tsunami attacked the coasts of northern Sumatra and Thailand, which are close to the tsunami source region. Also, the energy radiation pattern suggests that the tsunami had the directivities to propagate westward and eastward, attacking the coasts of Sri Lanka, and Maldives. Figs. 1.7, 1.8, and 1.9 are the computed local tsunami heights along the coasts of northern Sumatra, Thailand, Sri Lanka, southern India, and Maldives. These results are qualitatively consistent with the significance of reported tsunami damage and casualties.

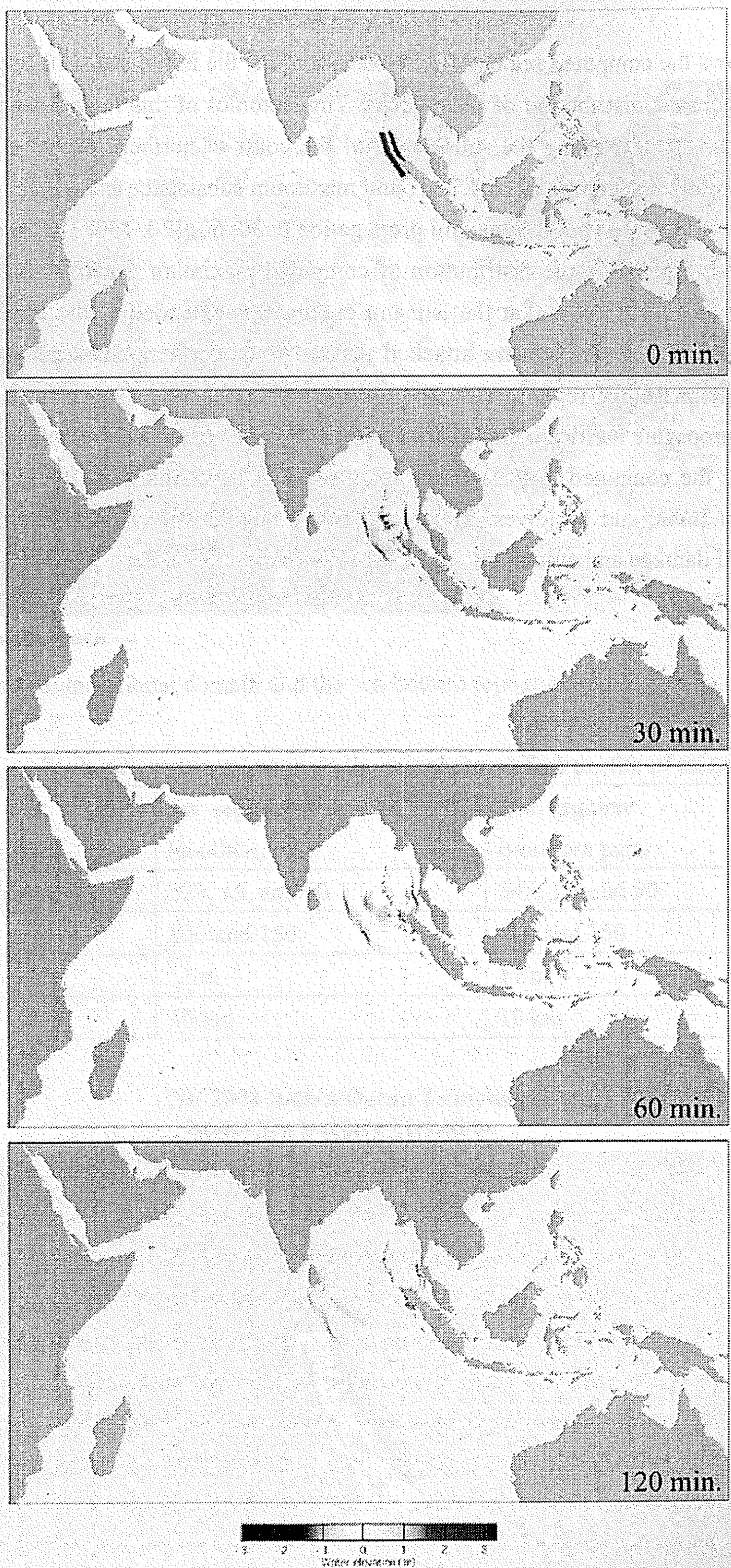


Fig. 1.5 Snapshots of the modeled tsunami propagating in the Indian Ocean

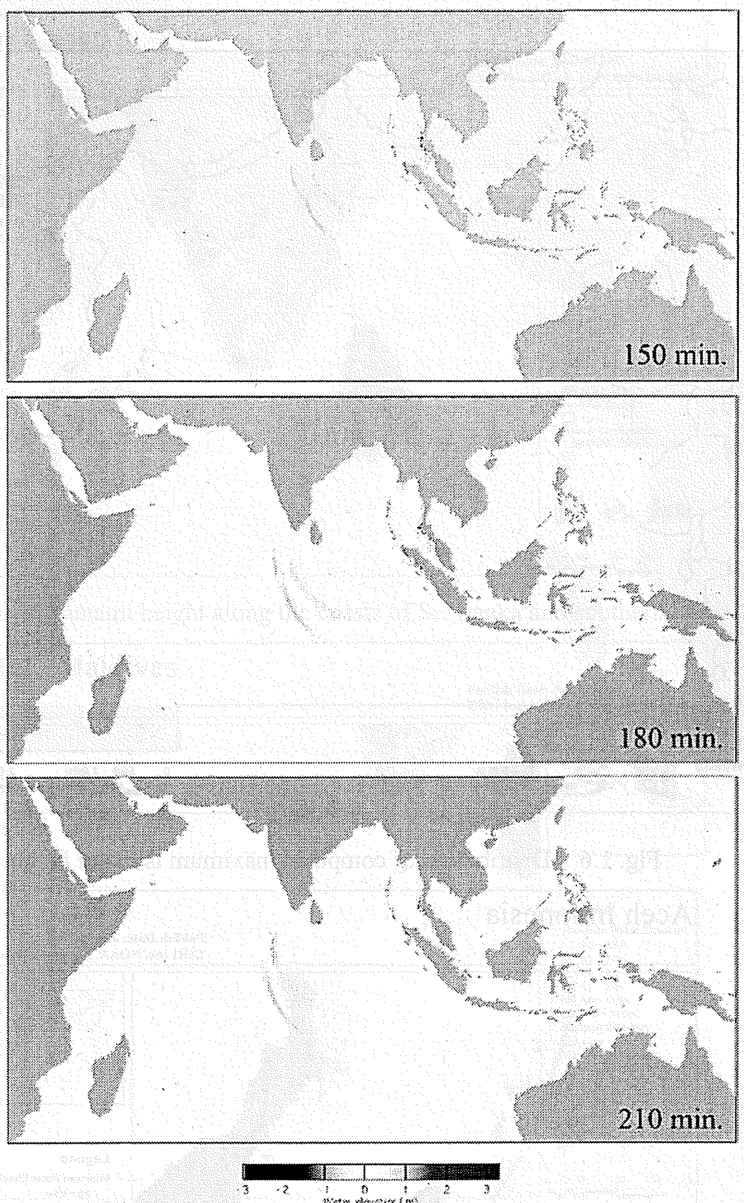


Fig. 1.5 (continued) Snapshots of the modeled tsunami propagating in the Indian Ocean

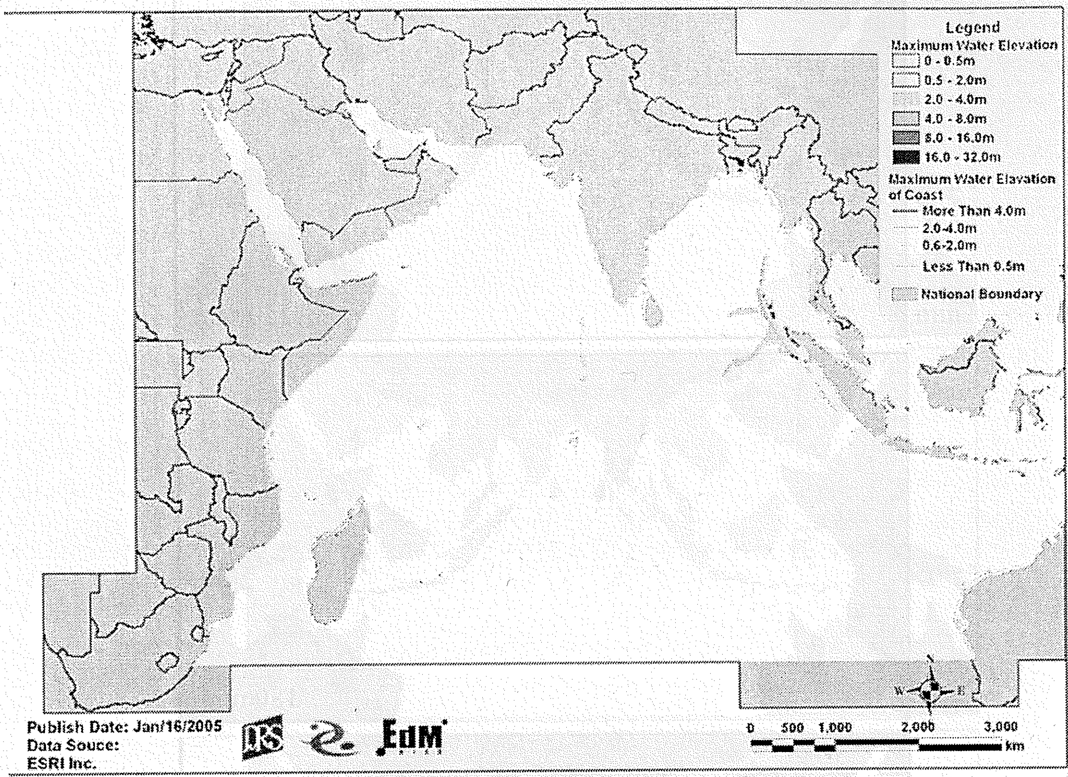


Fig. 1.6 Distribution of computed maximum tsunami height

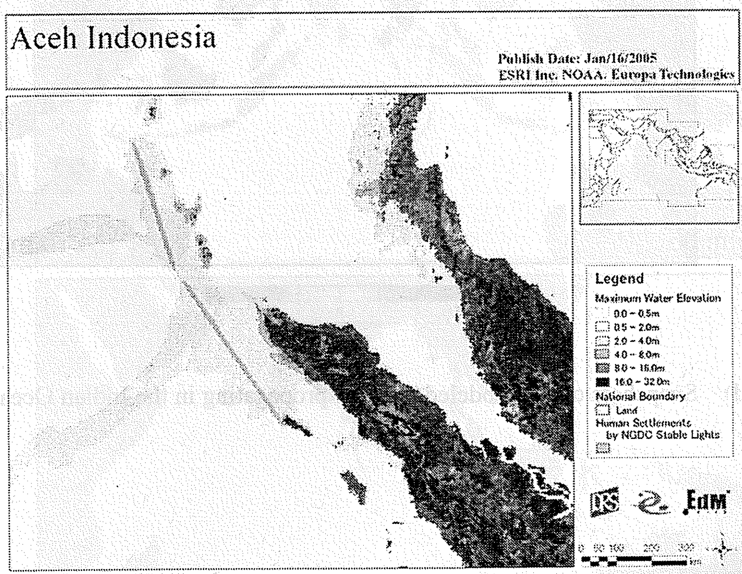


Fig. 1.7 Computed local tsunami height along the coasts of northern Sumatra and Thailand

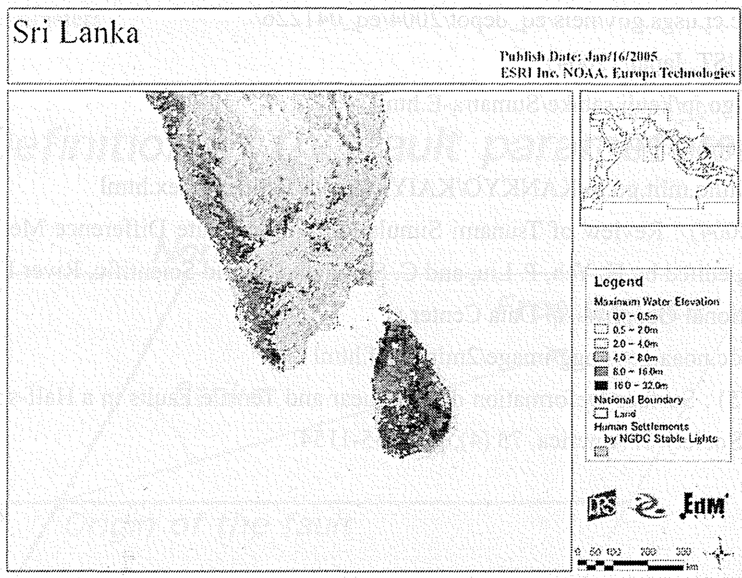


Fig. 1.8 Computed local tsunami height along the coasts of Sri Lanka and southern India

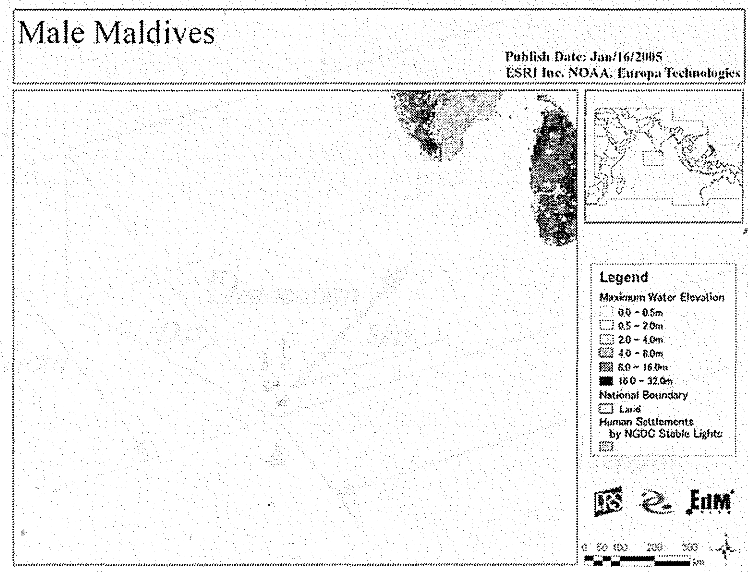


Fig. 1.9 Computed local tsunami height along the coasts of Maldives

1.3 Summary

From the preliminary numerical model runs, we attempted to comprehend the propagation characteristics of the 2004 December Indian Ocean tsunami. The model results are qualitatively consistent with the reported damage. However, we have not known yet the detailed source mechanisms; how significant tsunami along the coast of the source region could be generated by the M9.0 earthquake, and the whole picture of tsunami propagation characteristics and the tsunami risk within the Indian Ocean. Further investigations should be carried out with the results of post tsunami survey, and the analysis of observed tsunami records, strong ground motions, and measurement of crustal deformation of the source region.

References

(1) Web site of United States Geological Survey (2004) :

http://wwwneic.cr.usgs.gov/neis/eq_depot/2004/eq_041226/

(2) Kenji Satake, AIST, Japan (2004) :
http://staff.aist.go.jp/kenji.satake/Sumatra-E.html

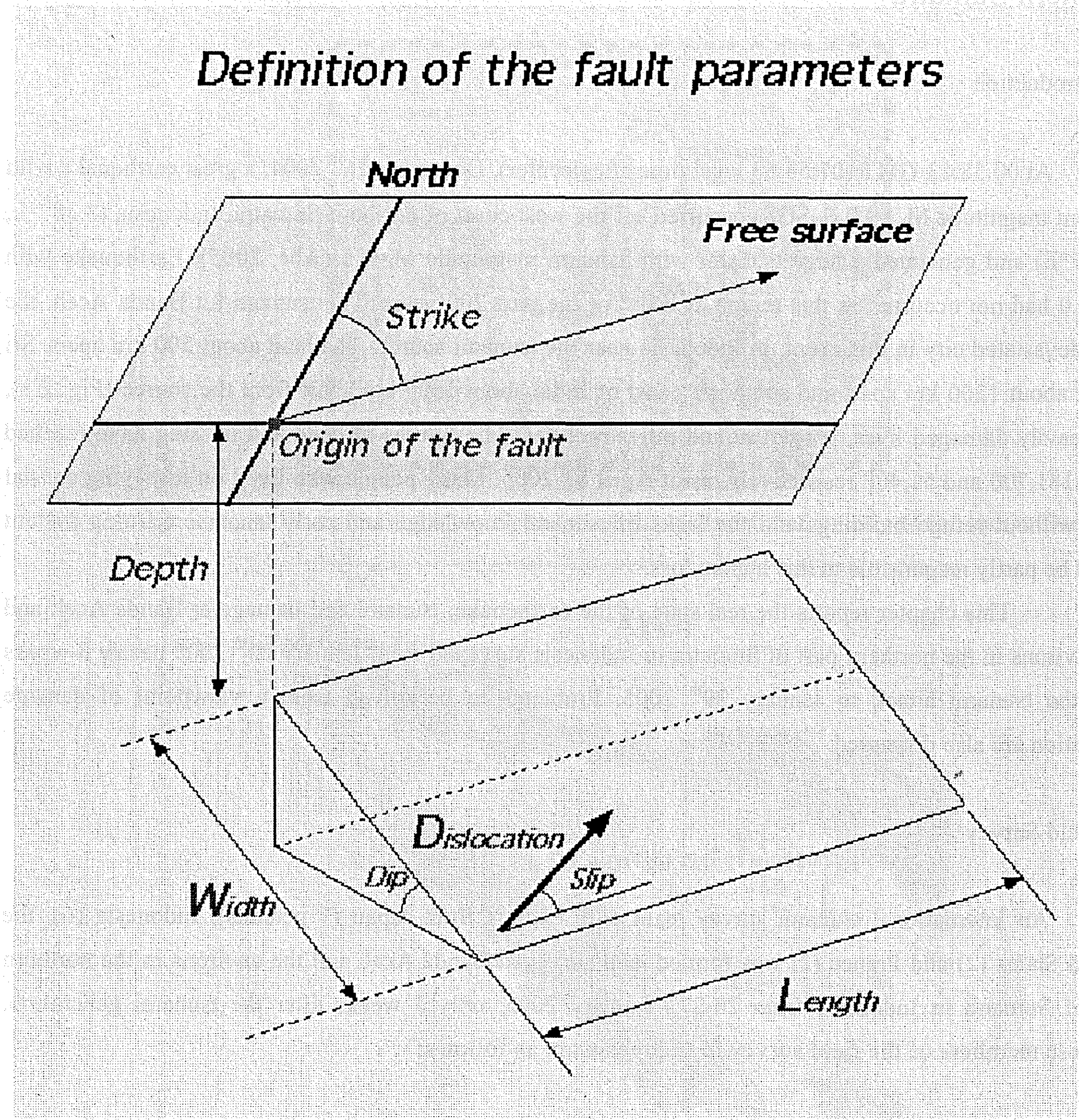
(3) Japan Coast Guard (2004) :
http://www1.kaiho.mlit.go.jp/KANKYO/KAIYO/jare/tide/tide_index.html

(4) Imamura, F. (2004) : Review of Tsunami Simulation with a Finite Difference Method, in Long-Wave Runup Models, edited by H. Yeh, P. Liu, and C. Synolakis, World Scientific, River Edge, NJ, pp.43-87.

(5) Web site of National Geophysical Data Center :
http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

(6) Okada, Y. (1985) : Surface Deformation due to Shear and Tensile Faults in a Half-space, Bulletin of the Seismological Society of America, 75 (4), pp.1135-1154.

Appendix : Fault parameters



Chapter 2 Earthquake, Tsunami and Damage at Banda Aceh and the Environs in Northern Sumatra

2.1 Introduction

At 00:58:53 GMT (07:58:53 local time at epicenter), December 26th 2004, a great earthquake with moment magnitude M_w=9.0 (USGS) occurred off the west coast of northern Sumatra, Indonesia (3.307°E, 95.947°E) and generated a huge tsunami with tsunami magnitude M_t=9.1 (Abe, 2005). Earthquake with $M_w \geq 9.0$ had not occurred in this region at least for the past 200 years. The tsunami hit Banda Aceh, the most devastated city in this event, in Indonesia near the tsunami source, Thailand about 500 km apart, Sri Lanka about 1200 km apart and southeast coast of India about 1500 km apart from the source (Fig. 2.1), and heavily damaged lives, properties and infrastructures. The figures of dead and missing have reached about 181,700 and 51,400 respectively, as of April 8th 2005. Many people who lived on low-lying coastal areas without refuge buildings and the lacks of tsunami knowledge and early tsunami warning system would be partly responsible to this human loss.

This chapter reports the real state of the earthquake, tsunami and damage at Banda Aceh and the environs in the northern part of Sumatra in Indonesia surveyed from January 20th 2005 nearly 3 weeks after the tsunami attack to January 29th 2005. Problems to be solved from a viewpoint of damage estimation are also discussed.

2.2 Field Survey

An international tsunami survey team with experts from Japan (7 persons), Indonesia (6), the United States (2) and France (2) was formed, and surveyed Banda Aceh and the environs in the northern part of Sumatra in Indonesia from 20-27th January 2005, only 3 weeks after the tsunami generation. Japanese members of the field survey in Indonesia are as follows:

Takanobu KAMATAKI (National Institute of Advanced Industrial Science and Technology)
Hideo MATSUTOMI (Akita University)
Yoshikane MURAKAMI (Kansai Electric Power, co., inc.)
Yuichi NISHIMURA (Hokkaido University)
Tsutomu SAKAKIYAMA (Central Research Institute of Electric Power Industry)
Yuichiro TANIOKA (Hokkaido University)
Yoshinobu TSUJI (University of Tokyo) Leader of the survey team

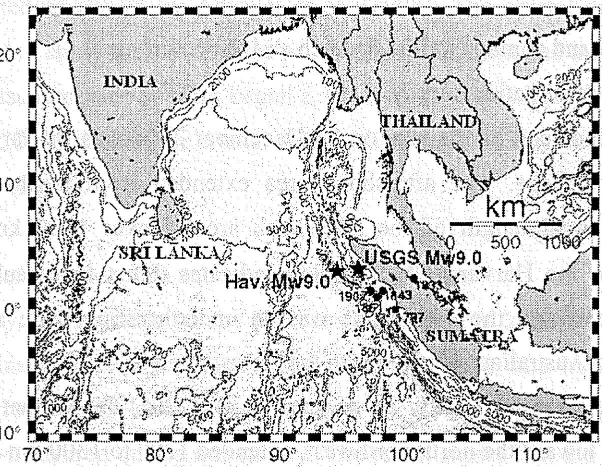


Fig. 2. 1 Epicenters of the present (★) and past (•) earthquakes and bathymetry of the Indian Ocean.

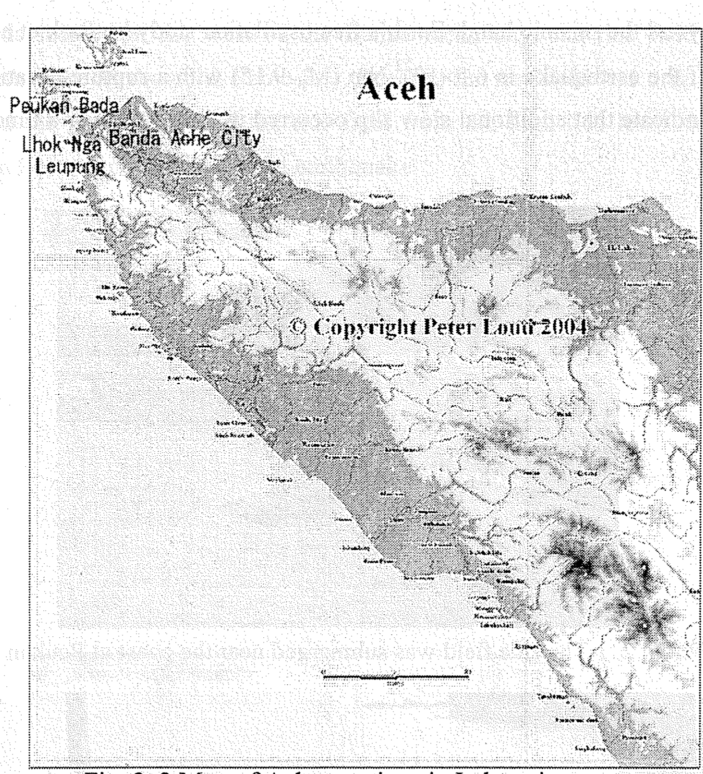


Fig. 2. 2 Map of Ache province in Indonesia.

Major points of the field survey are:

1) Coseismic crustal deformation.
2) State of tsunami attack.
3) Tsunami heights and their distribution.
4) Current velocity and fluid force of inundated flow (Matsutomi, 1993).
5) Tsunami deposit.
6) Damage to buildings, coastal and harbor structures, oil storage tanks and so on.

Survey areas are shown in Figs. 7 and 8 (enlarged). The areas are Banda Aceh, Lhoknga on the west coast, Sigli on the east coast, and both north and south coasts in Weh Island.

2.3 Earthquake, tsunami and damage at Banda Aceh and the environs

2.3.1 Coseismic crustal deformation survey

The Sumatra-Andaman earthquake on 26 December 2004 was the largest in the world since the 1964 great Alaska earthquake. The aftershock area extended from northwest of Sumatra Island to Andaman Islands. The total length of the aftershock area is over 1200 km. The mechanism of the earthquake according to the Harvard CMT catalog indicates thrust type faulting (strike=329°, dip=8°, rake=110°). This suggests that the earthquake was an underthrusting plate boundary event due to the subduction of the Indian-Australian plate beneath the Eurasian plate.

The teleseismic waveform study by Ammon et al. (2005) shows that the rupture expanded at a speed of about 2.5 km/s toward the north northwest, extended 1200 to 1300 km along the Andaman trough. They also suggested that the some slip in the northern 400 to 500 km of the aftershock zone have occurred on a time scale beyond the seismic band. Earth's free oscillation study by Park et al. (2005) shows that the seismic moment of the earthquake is 6.5×10^{22} Nm (M_w 9.15) with a rupture duration of 600 seconds. Lay et al. (2005) also indicate that additional slow slip occurred in the north over a time scale of 50 minutes or longer.

Photo 2. 1 The rice field was submerged near the coast at Peukan Bada.

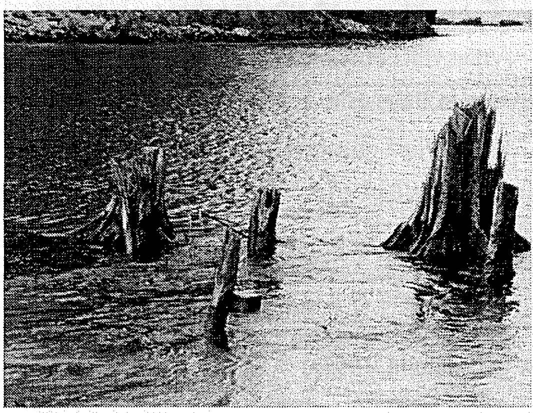


Photo 2. 2 Trees were submerged at Leupung (left) and Lhok Nga (right).

All of the above results suggest that unusual slow slip nature was a part of the source process of the 2004 Sumatra-Andaman earthquake. However, the qualitative analysis of the slow slip nature using seismological data is limited as shown by Ammon et al. (2005). The crustal deformation and tsunami waveform data are essential to study the slow source processes of the event and tsunami generation.

Our international tsunami survey team began a 10-day long investigation in the Ache province in Indonesia from January 20, 2005. Coseismic crustal deformation data and tsunami waveforms data are also collected during the survey (Fig. 2. 2).

2.3.1.1 Coseismic crustal deformation data and tsunami waveform data

In Banda Ache city, the geodetic survey has been conducted in 2002 by the local government in order to construct the drainage system in the city. We could get those data from the local government. Although the tsunami destroyed most of the structures near the coast, several survey points measured in 2002 was remained and re-measured during our survey. The result shows that the subsidence of 20-60 cm occurred in Banda Ache City (Fig. 2. 2).

At Peukan Bada located at the west of the Banda Ache city, the rice field near the coast is submerged after the earthquake as shown in Photo 2. 1. Because the rice field was originally above a high tide level, we measured the ground level of the rice field from the high tide level. It suggests that the subsidence of more than 20cm occurred due to the earthquake.

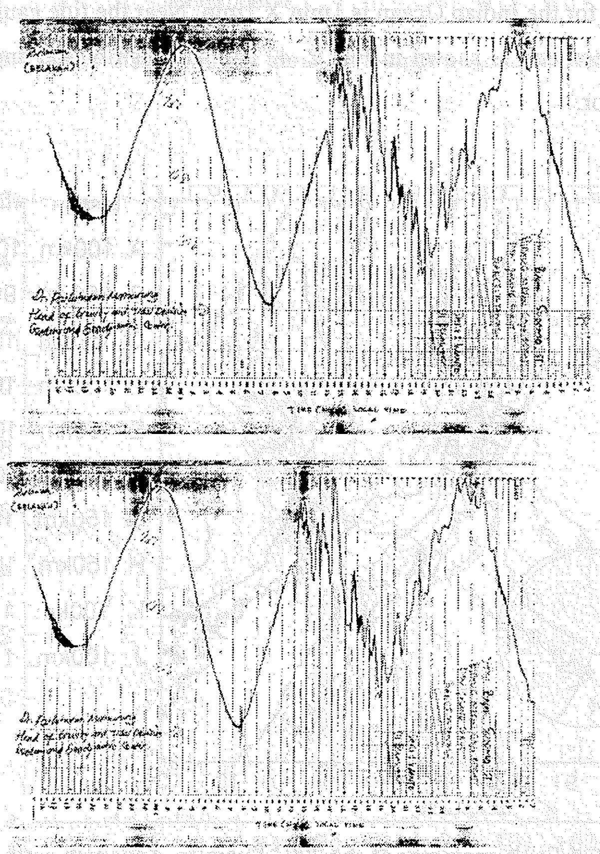


Fig. 2. 3 Tsunami waveforms at Belawan (upper) and Sibolga (lower).

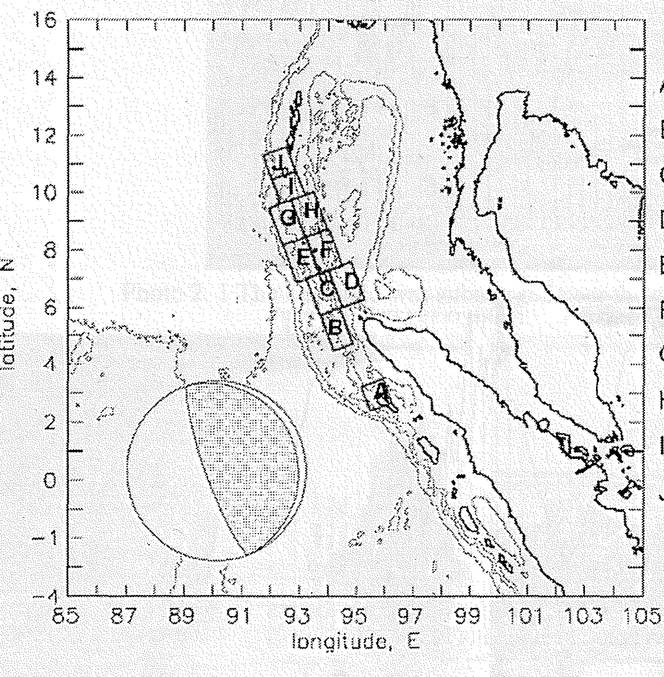
At Lhok Nga and Leupung located along the west coast of Ache province, some of the trees along the coast are also submerged after the earthquake as shown in Photo 2. 2. We measured ground levels at roots of the trees from the high tide levels. It suggests that the subsidence of more than 1.5m occurred there. The subsidence can be due to the erosion caused by tsunami. Therefore, the subsidence due to the earthquake might be smaller than our estimates in this area.

Analog tsunami waveforms recorded at two tide gauges, Sibolga and Belawan was collected during the survey (Fig. 2. 3).

2.3.1.2 Analysis

Tanioka et al. (2005) study the source process of the 2004 Sumatra-Andaman earthquake using the above coseismic crustal deformation data, tsunami waveforms observed at two tide gauges, and the data collected by the other surveys. Additional data are the tsunami waveform observed at Colombo by the National Aquatic Resources Agency in Sri Lanka, tsunami waveforms observed at Port Blair and Vishakhapatnam by the National Institute of Ocean Technology and National Geophysical Research Institute in India, the coseismic crustal deformation data in Simeulue Island observed by the other international tsunami survey team in Indonesia.

The tsunami waveforms are numerically computed using the actual bathymetry. The linear long wave equations with the Coriolis force are solved using finite-difference calculations on a staggered grid system. The grid spacing for the Indian Ocean is 1min X 1min. Near the tide gauges, the grid spacing is 20 sec x 20sec. The fault geometry is shown in Fig. 2. 4. The slip distribution and the rupture velocity are estimated by trial and error.



	Length	width	depth
A:	100km	100km	10km
B:	150km	90km	10km
C:	150km	100km	10km
D:	150km	100km	27km
E:	150km	100km	5km
F:	150km	100km	22km
G:	150km	100km	5km
H:	150km	100km	22km
I:	100km	110km	10km
J:	100km	110km	10km

Fig. 2. 4 Fault geometry of the 2004 Suamtra-Andaman earthquake

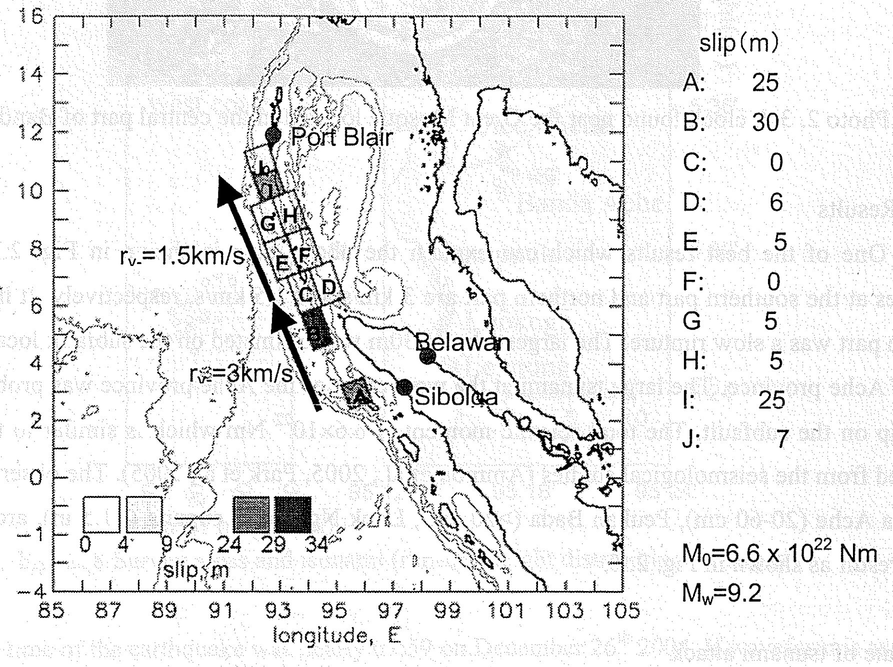


Fig. 2. 5 The slip distribution of the 2004 Sumatra-Andaman earthquake

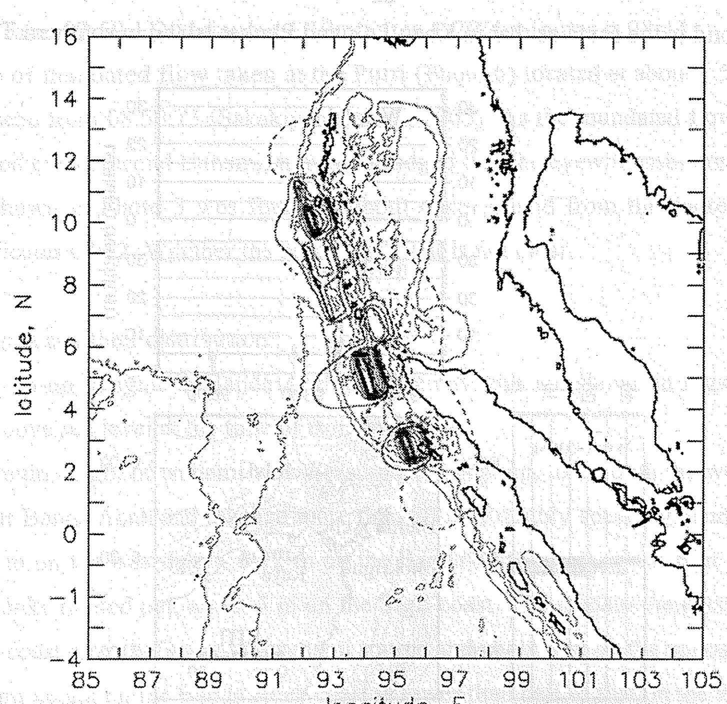


Fig. 2. 6 Coseismic vertical deformation due to the Sumatra-Andaman earthquake. Dash lines show the subsidenceand solid red line show the uplift.

Photo 2. 3 A clock found near the Great Mosque located in the central part of Banda Aceh.

2.3.1.3 Results

One of the best results which can explain the above data is shown in Fig. 2. 5. The rupture velocities at the southern part and northern part are 3 km/s and 1.5 km/s, respectively. It indicates that the northern part was a slow rupture. The largest slip of 30m was estimated on the subfault located off the west coast of Ache province. The large tsunami at the west coast of the Ache province was probably due to this large slip on the subfault. The total seismic moment is 6.6×10^{22} Nm which is similar to the other results estimated from the seismological studies (Ammon et al., 2005, Park et al, 2005). The observed subsidences at Banda Ache (20-60 cm), Peukan Bada (>20 cm), Lhok Nga and Leupung (>1.5 m), are well explained by this result as shown in Fig. 2. 6.

2.3.2 State of tsunami attack

According to eyewitnesses at Ulee Lheue in Band Aceh located at ★ in Fig. 2. 8, the first tsunami reached shore 15-20 minutes after the earthquake, the time interval between the first and second tsunamis was 15-20 minutes, and the first was bigger than the second. The eyewitness that the first was bigger than the second is the same as that in Khao Lak and Phuket Island in southern Thailand (Matsutomi et al., 2005).

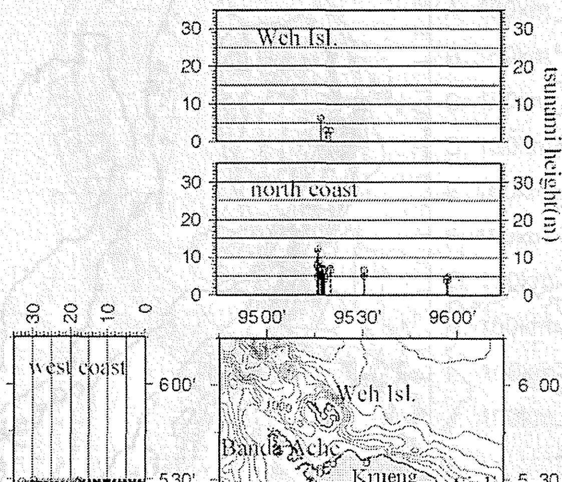


Fig. 2. 7 Survey areas and tsunami (run-up) height distribution.

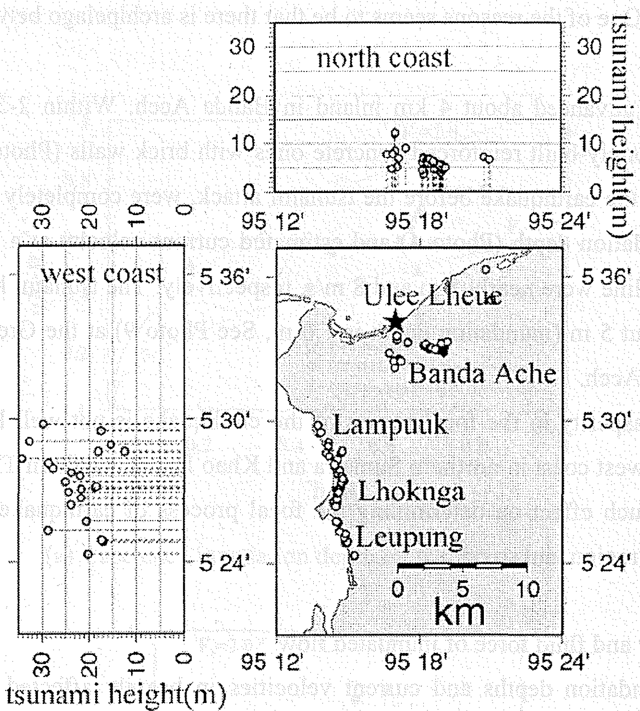


Fig. 2. 8 Survey areas and tsunami (run-up) height distribution (enlarged).

Origin time of the earthquake was nearly 07:59 on December 26th 2004. If waveform is assumed to be a trigonometric function, the fastest and latest arrival times of the second tsunami are estimated as follows:

The fastest case: 07:59 + 15 minutes + 15minutes + 15/4 minutes ≅ 08:33

The latest case: 07:59 + 20 minutes + 20minutes + 20/4 minutes ≅ 08:44

The video of inundated flow taken at the Putri (Photo 6) located at about 1.5 km inland from the shore shows the scene from 08:50:23 (Sakakiyama et al., 2005). As the inundated flow in the video seems to be the peak period of the second tsunami, it may be judged that the eyewitnesses are fairly sure.

A clock shown in Photo 3 was found at about 4 km inland from the shore, the central part of Banda Aceh. It indicates 08:12. Whether the clock was right is not clear.

2.3.3 Tsunami heights and their distribution

Tsunami (run-up) heights in Banda Aceh and the environs are shown in Figs. 7 and 8. These are corrected to ones above sea level at the time of tsunami attack.

The maximum height of tsunami was measured at Leupung, located on the west coast of northern tip of Sumatra, near Banda Aceh and reached more than 30 m. Roughly speaking, tsunami heights in other coasts were 15-30 m on the west coast, 6-12 m on the Banda Aceh coast, about 6 m on the Krueng Raya coast where 3 oil tanks floated out, about 5 m on the Sigli coast. The tsunami heights in Weh Island were 3-6 m on the north coast directly facing the tsunami source and about 3 m on the opposite side of the coast.

The tsunami height on the Banda Aceh coast is lower than half of that on the west coast. Even within the Banda Aceh coast, the tsunami height reduces by half from 12 m at Ulee Lheue to 6 m at about

8 km apart northeast. One of the reasons seems to be that there is archipelago between Lhoknga and Banda Aceh (Fig. 2. 8).

The tsunami advanced about 4 km inland in Banda Aceh. Within 2-3 km from the shoreline, houses except for strongly-built reinforced concrete ones with brick walls (Photo 4), which seemed to be partially damaged by the earthquake before the tsunami attack, were completely swept away or destroyed by the tsunami. Inundation depth (Photo 4) and estimated current velocity at a distance of about 0.9 km inland from the shoreline were nearly 5 m and 8 m/s, respectively. The tsunami height reduced from 12 m at Ulee Lheue to about 5 m (inundation depth is 1.6 m. See Photo 9) at the Great Mosque located in the central part of Banda Aceh.

Location of asperity in the focal region of the earthquake is not well known (Yagi, 2005). The huge tsunamis at the west coast in northern Sumatra and Khao Lak in southern Thailand (Matsutomi et al., 2005) would have much effect on determining the focal process of earthquake, the initial waveform of tsunami in the source region and so on.

2.3.4 Current velocity and fluid force of inundated flow

Data on inundation depths and current velocities in heavily affected areas were energetically collected to discuss the strength and criterion for destruction of buildings, which would be useful, for example, to estimate tsunami damage and to build refuge buildings.

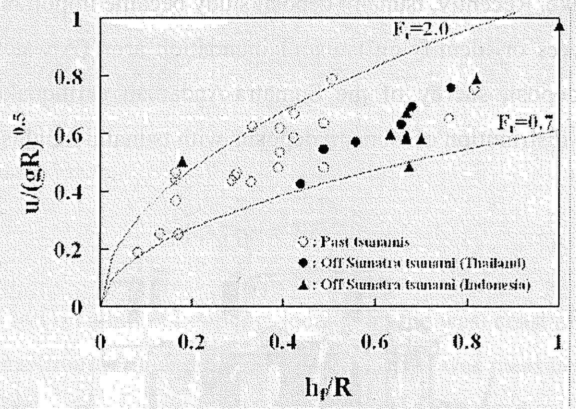
Figures 9(a) and 9(b) show the relation between the inundation depth h and the current velocity u, where the subscripts f and r distinguish between the front and rear sides of structure such as house. They are nondimensionalized by the gravitational acceleration g and the nearest tsunami (run-up) height R. The filled circles and triangles are data collected from this tsunami, and the opened circles are data collected from past tsunamis. The solid lines in Figures 9(a) and 9(b) are Equations (1) and (2) for two different values of F_r and envelopes for the field data (Matsutomi and Iizuka, 1998).

$$\frac{u}{\sqrt{gR}} = \sqrt{\frac{2C_v^2 F_r^2}{F_r^2 + 2C_v^2}} \sqrt{\frac{h_f}{R}} \tag{1}$$

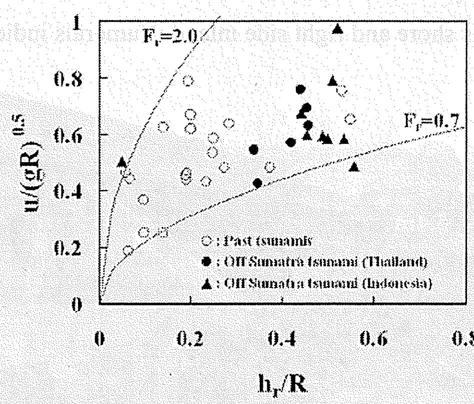
$$\frac{u}{\sqrt{gR}} = F_r \sqrt{\frac{h_r}{R}} \tag{2}$$

where C_v (=0.8-0.9) is the velocity coefficient and F_r (= $u/\sqrt{gh_r}$) the Froude number. From the figures, it is clear that the data from this tsunami has the same tendency as that from the past tsunamis.

Photos 4-6 show examples of variation of the inundation depth, current velocity and so on due to the distance from shoreline. The judgments of degree of damage to houses are based on the criterion of destruction defined by Matsutomi and Shuto (1994).



(a) Case used inundation depth on the front side



(b) Case used inundation depth on the rear side

Fig. 2. 9 Relation between nondimensionalized inundation depth and current velocity.

These are all examples at low-lying coastal area in Banda Aceh. The distance, inundation depth, current velocity and drag force *F* (dominant force (Matsutomi et al., 2004)) per unit area are (0.9 km, 4.9 m, 7.7 m/s, 6.2 tf/m^2 (6.1×10^4 Pa)), (1.3 km, 4.0 m, 5.2 m/s, 2.9 tf/m^2 (2.8×10^4 Pa)) and (1.5 km, 3.9 m, 5.8 m/s, 3.5 tf/m^2 (3.4×10^4 Pa)), respectively. The current velocity and drag force are estimated by the following equations:

$$u = \sqrt{2g(h_f - h_r)} \tag{3}$$

$$F = \rho C_D u^2 a/2 \cong \rho q u \tag{4}$$

where ρ is the density of seawater, C_D (≅2) the drag coefficient, a the unit area and q the flow rate per unit area.

The current velocity was estimated by using tsunami traces left on a hill (Photo 7). The current velocity of about 16 m/s and drag force of about 26.9 tf/m^2 (2.6×10^5 Pa) were estimated in front of a cement factory at Leupung. Traces on a hill seem to be useful to estimate the current velocity in huge tsunami.

2.3.5 Tsunami deposit survey

The Sumatra-Andaman earthquake on 26 December 2004 was the largest in the world since the 1964 great Alaska earthquake. Recently, tsunami deposit study became important for estimating recurrence intervals of great earthquakes or identifying tsunami inundation area (Atwater, 1987, Nanayama et al., 2004, etc). The tsunami deposit survey of the Sumatra-Andaman earthquake will provide a variable opportunity to compare the distribution of tsunami deposits with tsunami heights or inundation area.

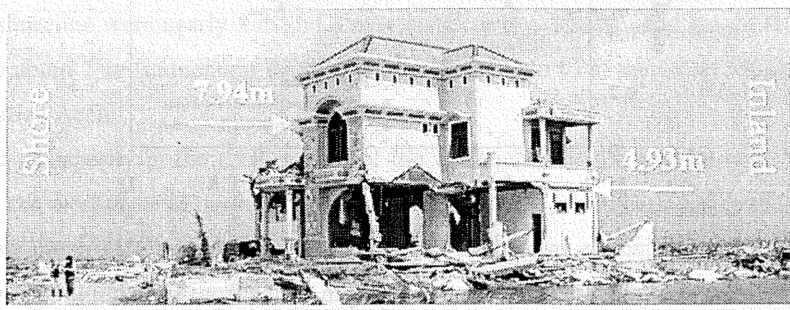


Photo 4 Partially damaged family house located at a distance of about 0.9 km inland from the shoreline in Banda Aceh. Left side is shore and right side inland. Numerals indicate inundation depths.

Photo 5 Partially damaged family house located at a distance of about 1.3 km inland from the shoreline in Banda Aceh. Left side is shore and right side inland. Numerals indicate inundation depths.

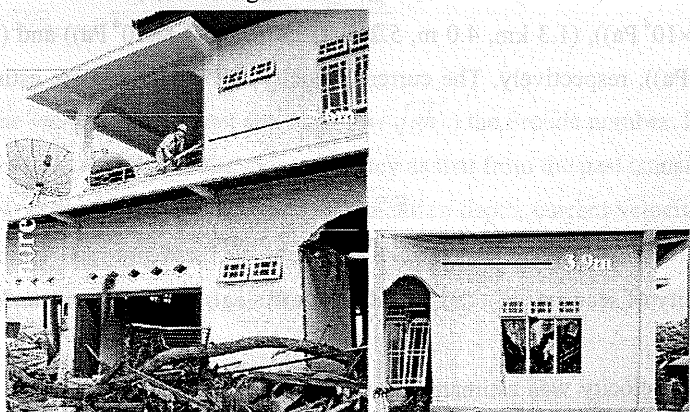


Photo 6 Partially damaged family house located at a distance of about 1.5 km inland from the shoreline in Banda Aceh. Left side is shore and right side inland. Numerals indicate inundation depths.

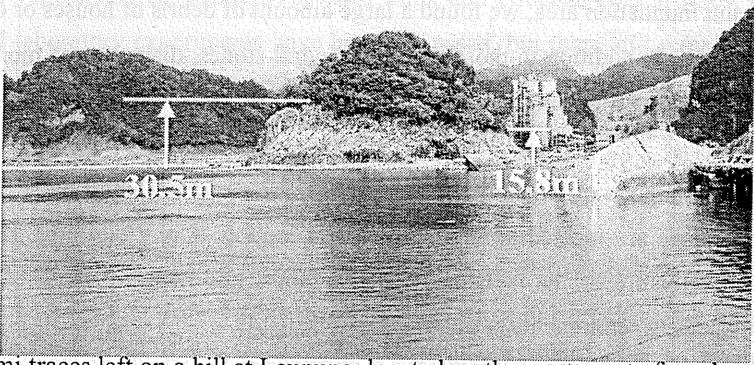


Photo 7 Tsunami traces left on a hill at Leupung, located on the west coast of northern tip of Sumatra. The maximum tsunami height of nearly 35 m was measured near here.

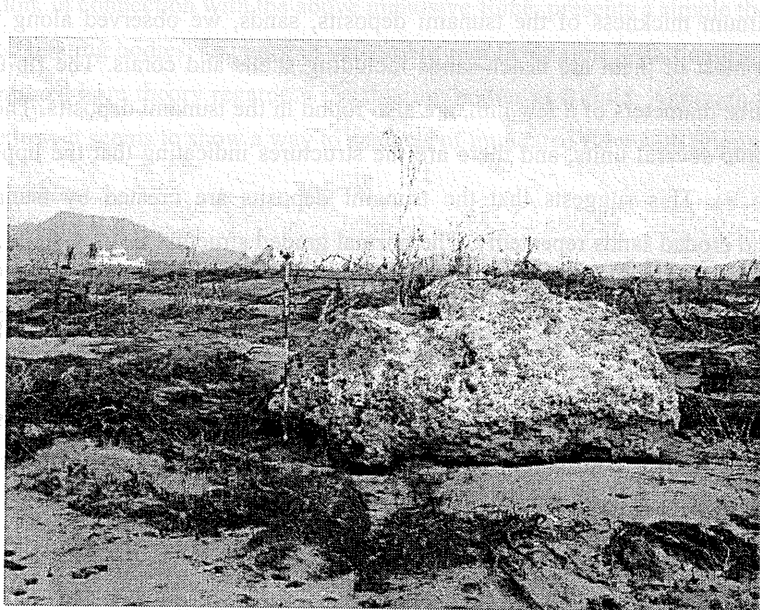


Photo 8 A coral stone deposited by the tsunami at Lhok Nga.

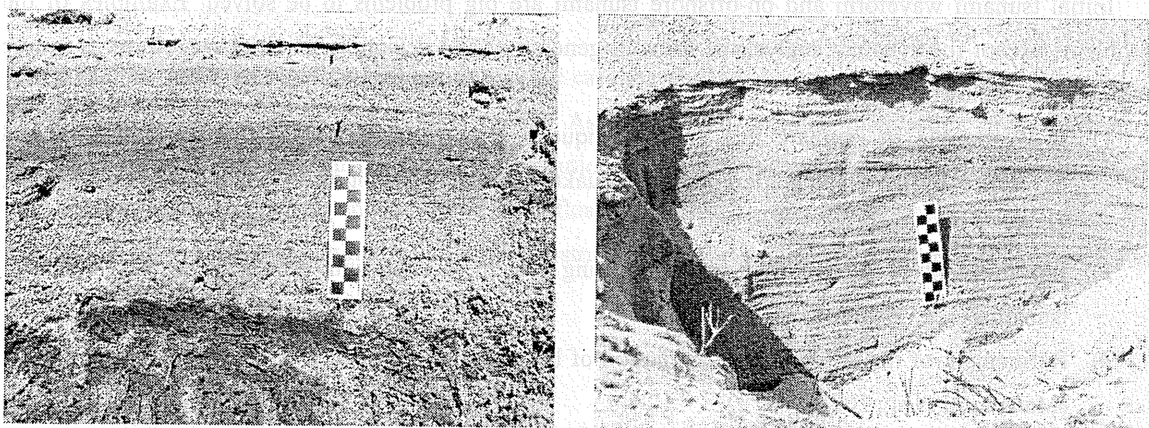


Photo 9 Tsunami deposits, sands, in the trenches along the survey line at Lhok Nga.

2.3.5.1 Tsunami deposit

In the tsunami inundation area, we found a large amount of debris of houses or other constructions destroyed by the tsunami. In addition to those, we found coral stones, diameters of more than 1m, carried by the tsunami from the ocean (Photo 8) and a large amount of sands from the beach. Those are called "Tsunami deposits".

The detail distributions of tsunami deposits, sands, are surveyed along three lines from beach to inland. Those survey lines are located at Lhok Nga and Leupung. Along the lines, several trenches are made to observe the structure of the tsunami deposits, sands, and measure thicknesses of sand layers (Photo 9). The distance between trenches is about 100-50 m.

2.3.5.2 Results

The maximum thickness of the tsunami deposits, sands, we observed along the three lines, is about 70 cm. The most of them are beach-sands including shells and corals. The rip-up clasts from the original soil deposits, diameters of a few mm, are also found in the tsunami deposits. The tsunami deposits can be separated into several units, and there are the structures indicating that the upper unit eroded the lower unit (Photo 9). This suggests that the tsunami deposits are created by tsunami waves which deposited sands and eroded sands repeatedly. The normal graded structure inside a unit is also found in the most of the units (Photo 9). In general, the thickness of the tsunami deposits decreases when the distance from the coast increases, although the thickness of the tsunami deposits is very much affected by the local topography.

Flow directions of the tsunami are also estimated from the direction of grasses or trees fallen down by the tsunami and the distribution of debris around large trunks of trees. The flow direction was found to be almost perpendicular to the coastline.

2.4 Problems from a viewpoint of damage estimation

Initial tsunami waveform and on-offshore tsunami are big problems to be solved. Examples of the problems except for dynamic analysis of tsunami generation and detection of initial waveform in source region are as follows:

1) Is it possible to estimate this great earthquake with M_w=9.0 with the conventional method developed by the Headquarters for Earthquake Research Promotion in Japan (Matsutomi et al., 2005).
2) Improvement of the present tsunami warning system to cope with great earthquakes and huge tsunamis (see Chapter 4).
3) Refinement of the criterion for destruction of buildings and influence of ground erosion on them (Matsutomi et al., 2005).
4) Generalization of method of estimating current velocity (Photos 4-6).
5) Method of estimating current velocity by use of a hill (Photo 7).
6) Increase of destructive force and current velocity of inundated flow with floating bodies.
7) Effect of coastal forest on reducing tsunami energy.

The problem 6) is discussed in the following section. In the problem 7) governing equations for inundated flow in vegetated area, similarity law for trunk and effect of coastal forest based on reports of past tsunamis and laboratory experiments have been discussed, but there still remain a lot of problems to be solved, for example, similarity law for foliage and so on.

2.5 A simple theory of inundated flow with floating bodies

Inundated flows with floating bodies such as debris, driftwoods, cars, bikes and boats were videotaped at Banda Aceh and drew our attention. So did collision force of such floating bodies. These would be also problems to be solved immediately. Matsutomi (1999) took up impulsive force due to collision of driftwoods and developed a simple method of estimating it.

This section, in connection with the above impulsive force, presents a simple theory for estimating moving velocity of floating bodies, i.e., current velocity of inundated flow with floating bodies. The theory adopts the conventional bore theory regarding the floating bodies as a fluid. Although the applicability of the theory may be low, it seems to show a way to analysis of inundated flow with floating bodies.

2.5.1 Theory

Let us consider a steady bore with debris, oil and so on, and regard those as a fluid with the same density as those in the downstream region of the bore.

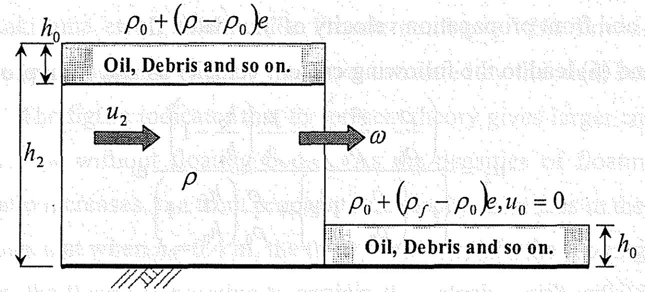


Fig. 2. 10 A simplified model of inundated flow with floating bodies and definition of symbols.

The model is shown in Fig. 2. 10. This figure is the case that the density of seawater is greater than that of the hypothetical fluid in the downstream region. As the vertical pressure distribution in the upstream region of the bore depends on the vertical distribution of the floating bodies, current velocity and bore propagation velocity also depend on that of the floating bodies. In this model, the floating bodies are swallowed up in the bore with maintaining their distribution in the downstream region, and then seawater gets into their void.

2.5.1.1 Continuity equation

The mass conservation law based on this model is as follows:

$$[\{\rho_0 + (\rho - \rho_0)e\}h_0 + \rho(h_2 - h_0)](\omega - u_2) = \{\rho_0 + (\rho_f - \rho_0)e\}h_0\omega \tag{5}$$

where ρ_0 is the density of floating bodies, ρ_f the density of void part in the downstream region (zero in case of air), e the void ratio of floating bodies in the downstream region, h_2 the water depth in the upstream region, u_2 the current velocity in the upstream region, h_0 the thickness of floating bodies layer in both the upstream and downstream regions, u_0 (=0) the current velocity in the downstream region, ω the bore (or front) propagation velocity.

The density in {} on the right hand side of Equation (5) is the mean density of the hypothetical fluid in the downstream region. When $\rho_0=\rho_f=\rho$, Equation (5) results in the mass conservation law of ideal bore.

2.5.1.2 Momentum equation

Assuming the hydrostatic pressure distribution, the momentum conservation law is as follows:

$$\left[\{\rho_0+(\rho-\rho_0)e\}h_0+\rho(h_2-h_0)\right](\omega-u_2)u_2=\rho g(h_2-h_0)^2/2 \\ +\{\rho_0+(\rho-\rho_0)e\}gh_2h_0-\{2(1-e)\rho_0+(\rho+\rho_f)e\}gh_0^2/2 \tag{6}$$

The hydrostatic pressure on the downstream side is taken into account in Equation (6). This is reasonable for real fluid such as oil, but there is room for reconsideration for debris and so on. If the hydrostatic pressure is ignored, the current velocity and front propagation velocity become larger than those in the case taken into account.

When $\rho_0=\rho_f=\rho$, Equation (6) results in the momentum conservation law of ideal bore.

2.5.1.3 Current velocity and front propagation velocity of inundated flow

Equations (5) and (6) lead to the following current velocity u_2 and front propagation velocity ω:

$$u_2=\frac{\left(\frac{\rho}{\rho_0}-\frac{\rho_f}{\rho_0}\right)e+\frac{\rho}{\rho_0}\left(\frac{h_2}{h_0}-1\right)}{\left\{1+\left(\frac{\rho}{\rho_0}-1\right)e\right\}+\frac{\rho}{\rho_0}\left(\frac{h_2}{h_0}-1\right)}\omega \tag{7}$$

$$\omega=\sqrt{g\left[\left\{\frac{\rho_0}{\rho}+\left(1-\frac{\rho_0}{\rho}\right)e\right\}h_0+h_2-h_0\right]\Big/\left\{1+\left(\frac{\rho_f}{\rho_0}-1\right)e\right\}\left\{\left(1-\frac{\rho_f}{\rho}\right)e+\frac{h_2}{h_0}-1\right\}} \\ \times\sqrt{\frac{1}{2}\frac{\rho}{\rho_0}\left(\frac{h_2}{h_0}-1\right)^2+\left\{1+\left(\frac{\rho}{\rho_0}-1\right)e\right\}\frac{h_2}{h_0}-\frac{1}{2}\left\{2(1-e)+\left(\frac{\rho}{\rho_0}+\frac{\rho_f}{\rho_0}\right)e\right\}} \tag{8}$$

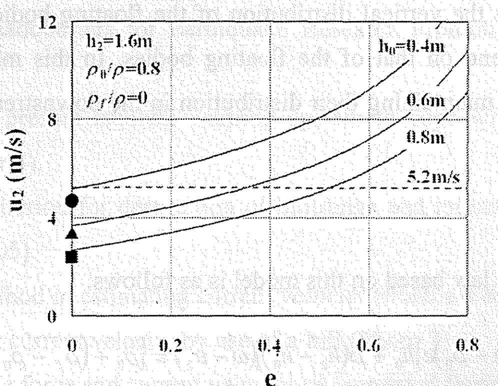


Fig. 2. 11 Examples of moving velocity of floating bodies (≅ current velocity).

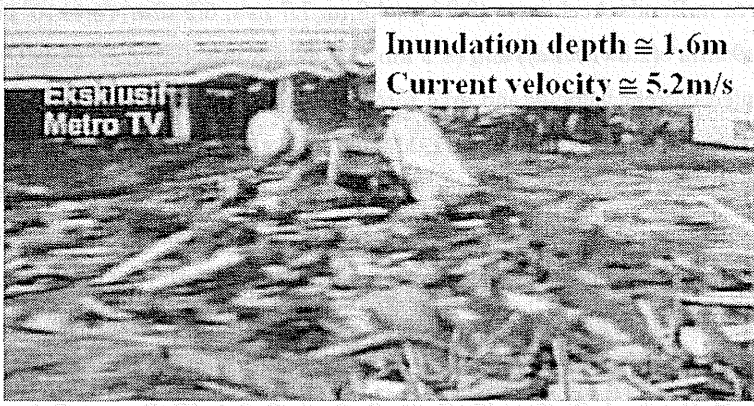


Photo 10 Inundated flow with floating bodies (just in front of the Great Mosque in Banda Aceh).

2.5.2 Example of solution

The moving velocity of floating bodies seems to be almost the same as the current velocity u_2 in a steady state. Examples of the solution of u_2 are shown in Fig. 2. 11. The conditions on h_2, ρ_0/ρ and ρ_f/ρ were determined by the video picture (Photo 10) taken just in front of the Great Mosque located in the central part of Banda Aceh and surveying the length and height of buildings in the video picture. The dotted line in the figure denotes the moving velocity of floating bodies (≅5.2 m/s) estimated by analyzing the video picture (Sakakiyama et al., 2005). The Froude number of this flow is about 1.3. Circle (●), triangle (▲) and square (■) denote the current velocities estimated by the ideal bore theory for h_0=0.4, 0.6 and 0.8 m, respectively. The figure indicates that the present theory gives larger current velocity compared with that of inundated flow without floating bodies. As the densities of floating bodies and void part decrease, and as void ratio increases, the front propagation velocity increases in the present theory.

Fig. 2. 11 denotes that when h_0=0.4 m, the theory can't explain the moving velocity of 5.2 m/s, but when h_0=0.6 and 0.8 m, the theory is possible to explain the velocity with e=0.35 and 0.52, respectively. As ρ_0 and h_0 are unknown in the Banda Aceh case, it is difficult to discuss further. Judging from the video picture, h_0 seems to be more than 0.4 m. Therefore, it may be concluded that the present theory is useful. It will be necessary to compare the theory with experimental results.

2.6 Summary

The main results in this section are:

1) The rupture velocities at the southern part and northern part of the focal region were 3 km/s and 1.5 km/s, respectively. The largest slip of 30 m was estimated on the subfault located off the west coast of Ache province. The total seismic moment of 6.6×10^{22} Nm was estimated.
2) The observed subsidences were 0.2-0.6 m at Banda Aceh, >0.2 m at Peukan Bada, >1.5 m at Lhok Nga and Leupung, and these were well explained by the proposed focal process.
3) Roughly speaking, tsunami heights were 15-30 m on the west coast, 6-12 m on the Banda Aceh coast, about 6 m on the Krueng Raya coast, about 5 m on the Sigli coast and 3-6 m in Weh Island.

4) The distance from shoreline, inundation depth, estimated current velocity and estimated drag force per unit area in Banda Aceh were (0.9 km, 4.9 m, 7.7 m/s, 6.2 tf/m^2 (6.1×10^4 Pa)), (1.3 km, 4.0 m, 5.2 m/s, 2.9 tf/m^2 (2.8×10^4 Pa)) and (1.5 km, 3.9 m, 5.8 m/s, 3.5 tf/m^2 (3.4×10^4 Pa)), respectively. The estimated current velocity and drag force were (16 m/s, 27 tf/m^2 (2.6×10^5 Pa)) in front of the cement factory at Leupung and (3.6 m/s, 1.3 tf/m^2 (1.3×10^4 Pa)) in Sigli.
5) The maximum thickness of the tsunami deposits was about 0.7 m. The tsunami deposits could be separated into several units and were created by repeated tsunami waves. The normal graded structure inside a unit was also found in the most of the units.
6) Several problems from a viewpoint of damage estimation were pointed out. A simple theory for the inundated flow with floating bodies was presented.

References

Abe, K.: Revised M_t and run-up estimate for the Indian Ocean Tsunami, A quick report contributed to the tsunami-japan (tsunami bulletin board in Japan) on January 27th 2005.

Ammon, J. C., C. Ji, H. Thio, D. Robinson, S. Ni, V. Hjorleifsdottir, H. Kanamori, T. Lay, S. Das, D. Helmberger, G. Ichinose, J. Polet and D. Wald: Rupture process of the 2004 Sumatra-Andaman earthquake, *Science*, 308, 1133-1139, 2005.

Asian Tsunami Videos: Amateur Asian Tsunami Video Footage, http://www.Asiantsunamivideos.com/, refered on 2005-3-30.

Atwater, B. F.: Evidence for great Holocene earthquakes along the outer coast of Washington State, *Science*, 236, 942-944, 1987.

BBC: bbc.co.uk homepage - Home of the BBC on the Internet, http://news.bbc.co.uk/, refered on 2005-2-28.

JSCE: Quick report meeting on the 2004 Indian Ocean Tsunami held by JSCE on January 14th 2005, http://www.jsce.or.jp/ report/33/, refered on 2005-1-31. (in Japanese)

Kamataki, T. and Y. Nishimura: Field survey of the 2004 Off-Sumatra earthquake tsunami around Banda Ache, northern Sumatra, Indonesia, *Jour. of Geography*, 114, 78-82, 2005. (in Japanese)

Lay, T., H. Kanamori, C. J. Ammon, M. Nettles, S. N. Ward, R. C. Aster, S. L. Beck, S. L. Bilek, M. R. Brudzinski, R. Butler, H. R. Deshon, G. Ekstrom, K. Satake and S. Sipkin, The great Sumatra-Andaman earthquake of 26 December 2004, *Science*, 308, 1127-1132, 2005

Matsutomi, H.: Tsunami and damage in the northeast part of Flores Island, *Kaiyo Monthly*, Vol.25, No.12, pp.756-761, 1993. (in Japanese)

Matsutomi, H. and N. Shuto: Tsunami inundation depth, current velocity and damage to houses, *Proc. of Coastal Eng., JSCE*, Vol.41, pp.246-250, 1994. (in Japanese)

Matsutomi, H., F. Imamura, T. Takahashi, K. Kurayoshi, K. Kobune, G. Watson, H. Rahman and N. Shuto: The 1996 Irian Jaya Earthquake Tsunami and Damage, *Proc. of Coastal Eng., JSCE*, Vol.43, pp.311-315, 1996. (in Japanese)

Matsutomi, H. and H. Iizuka: Tsunami current velocity on land and a simple method of estimating it, *Proc. of Coastal Eng., JSCE*, Vol.45, pp.361-365, 1998. (in Japanese)

Matsutomi, H.: A practical formula for estimating impulsive force due to driftwoods and variation features of the impulsive force, *Jour. of Hydraulic, Coastal and Environmental Eng., JSCE*, No.621/□-47, pp.111-127, 1999. (in Japanese)

Matsutomi, H., T. Ohmukai and K. Imai: Fluid force on a large structure due to an inundated flow caused by a tsunami, *Annual Jour. of Hydraulic Eng., JSCE*, Vol.48, pp.559-564, 2004. (in Japanese)

Matsutomi, H., T. Takahashi, M. Matsuyama, K. Harada, T. Hiraishi, S. Supartid and S. Naksuksakul: The 2004 Off Sumatra Earthquake Tsunami and Damage at Khao Lak and Phuket Island in Thailand, *Proc. of Coastal Eng., JSCE*, Vol.52, 2005. (in Japanese)

Nanayama, F., K. Satake, R. Furukawa, K. Shimokawa, B. F. Atwater, K. Shigeno, and S. Yamaki: Unusually large earthquakes inferred from tsunami deposits along the Kuril Trench, *Nature*, 424, 660-663, 2003.

Park, J., T. A. Song, J. Tromp, E. Okal, S. Stein, G. Roult, E. Clevede, G. Laske, H. Kanamori, P. Davis, J. Berger, C. Braitenberg, M. V. Camp, X. Lei, H. Sun, H. Xu and S. Rosat: Earth's free oscillations excited by the 26 December 2004 Sumatra-Andaman earthquake, *Science*, 308, 1139-1144, 2005

Royal Thai Navy: Tide gauge data, http://www.navy.mi.th/hydro/tsunami.htm, refered on 2005-3-30.

Sakakiyama, T., H. Matsutomi, Y. Tsuji and Y. Murakami: Comparison of Current velocities of Tsunami Inundated Flow Based on Analysis of Video Picture and Field Survey, *Abstract for the December 26, 2004 Off-Sumatra Earthquake meeting, Japan Assoc. for Earthquake Eng.*, pp.33-38, 2005.

Tanioka, Y., Yudhcara, T. Kusuniose and K. Satake: Analysis of a tsunami waveform and coseismic deformation for the 2004 Sumatra earthquake, *Abstract for the 2005 Japan Earth and Planetary Science Joint meeting*, J113, 2005.

Yagi, Y.: What Happened in the Focal region of the 2004 Off-Sumatra Great Earthquake ?, *Abstract for the December 26, 2004 Off-Sumatra Earthquake meeting, Japan Assoc. for Earthquake Eng.*, pp.1-5, 2005.

Yamanaka, K.: Earthquake Research Institute homepage, Univ. of Tokyo, http://www.eri.u-tokyo.ac.jp/sanchu/Seismo_Note/ 2004/EIC161a.html, refered on 2005-2- 21. (in Japanese)

Chapter 3 Field Survey Report on the 2004 Indian Ocean Tsunami in the Southwestern Coast of Sri Lanka

3.1 Introduction

The huge earthquake with the magnitude 9.0 took place at the northwest offshore of Sumatra Island in December 26, 2004. This earthquake generated the tsunami and caused the catastrophic disasters in all coastal area in the Indian Ocean. To investigate the damage which expanded to wide area the field survey is carried out in the each suffered countries under the international cooperation. This survey team is the part of the international survey mission, ITST(International Tsunami Survey Team), and the team surveyed the situation of tsunami run-ups and the damage at the southwest coast of Sri Lanka in 4th to 6th January, 2005.

Sri Lanka is located 1,700km far from the epicenter and the tsunami source, so no one felt the ground shake. The characteristic of this tsunami is a so-called Oceanic /distant Tsunami, and the tsunami attacked all coast in Sri Lanka around 2 hours after the earthquake. Sri Lanka (Population: 19,238,575, Total Area: : 65,610 sq km, Coastline: 1,340 km) is an oval island where it is close to the Indian Continent, and the sea bottom is connected from the deep ocean with the coast by the steep slope. It is a place the tsunami behaves as the boundary wave and was influenced by the reflection and diffraction wave.

The confirmed number of casualties exceeds 30,000, and it reaches more than 40,000 if the number of missing is added. It is important to clarify the reason why the number of the death toll increased so high. Furthermore, the tsunami caused the damage for the traffic/transportation facilities and infrastructures such as trains, railways, roads, ports and so on. Investigation of the damage conditions is also essential.

3.2 Field Survey

3.2.1 Measuring Tsunami Trace Heights

The team investigated the coast in the southwest part from Colombo to Galle cities in order to measure the tsunami trace/runup heights, to inspect the damage, and to correct the information of the tsunami. Table 1 shows the tsunami trace information on the investigated points after tidal correction. All data on the table 1 are reliable, in which traces of the tsunami are clear. And Fig. 1 shows the distribution of tsunami heights of the trace at the whole investigation areas. Here, H_v shows the height (m) of traces on the mean sea level, and D_h shows the distance (m) from the shore line to the measured point. The range of the astronomical tide at this region is about ±0.7m. Since the coastal area on the land is so flat and the inundation area is so wide, it is rather difficult to reach the end of runup. We could mostly measure the heights of tsunami traces on the tree and wall of damaged houses.

Table 1 Tsunami trace information on investigated points

Location	H_v (m)	D_h (m)	Position of trace	Survey time
Waligama	4.9	54	Exterior wall of a house	11:02, 05, Jan
Koggala Airport	9.3	64	Roof of a house	11:30, 05, Jan
Galle Port	6.0	190	Exterior wall of an office	13:35, 05, Jan
Dodanduwa	4.0	24	Exterior wall of a house	16:35, 05, Jan
Hikkaduwa Fishery Harbour	4.7	54	Interior wall of a house at second floor	09:40, 06, Jan
Kahawa	10.0	228	Palm tree	10:02, 06, Jan
Ambalangoda beach	4.7	50	Exterior wall of a house	11:50, 06, Jan
Beruwala Fishery Harbour	2.4	6	Interior wall of a building	13:10, 06, Jan
North Beach of Beruwala	4.8	50	Washed up tree	14:10, 06, Jan
Paiyagala Station	6.0	36	Interior wall of a house at second floor	14:40, 06, Jan
Panadura	5.6	150	Roof of a house	15:50, 06, Jan
Moratuwa Beach	4.4	10	Exterior wall of a house	17:10, 04, Jan

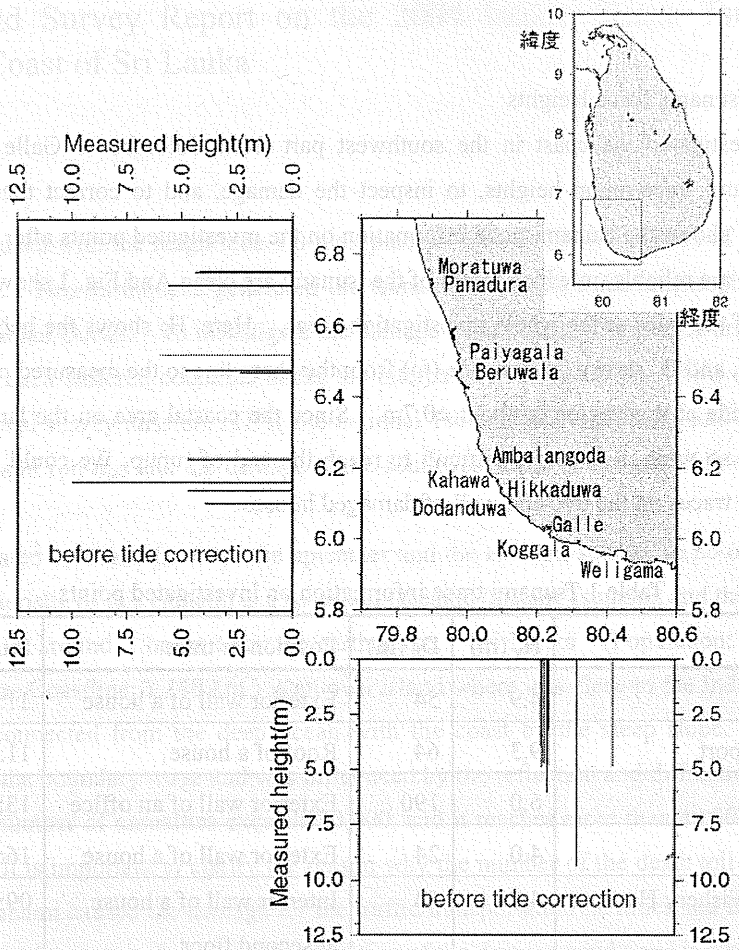


Fig. 1 Distribution of Tsunami Trace Heights in southwest Sri Lanka

From these table and figure, it is obvious that the tsunami trace heights were 6 m at the Galle port and 10 m at the Kahawa district which is located 90km in the south of Colombo. At the Beruwala district which is located 53km in the south of Colombo, though the tsunami trace heights was about 5 m, it was only 2.5m inside of the fishing port, suggesting the effect of the wave-break and sea wall here to reduce the tsunami attack. Details about this phenomenon are described in 3.3.2. It is indicated that the typical tsunami trace height s along the coast in the southwest of Sri Lanka was about 5m by the field survey, except for two points; Koggala airport and Kahawa.

3.2.2 Tsunami Arrival Time and attacks

There are several places where the number of tsunami attacks were two or three according to the eyewitnesses as shown in Fig. 2. The arrival time of the tsunami at the Galle port was estimated to be 9:25 AM in Sri Lankan time, and it is post at the Galle port office. At other districts, the arrival time of the first tsunami was estimated by the eyewitnesses to be 9:30AM at the Moratuwa district, 9:45 AM at the Kahawa and the Beruwala district. The occurrence time of the earthquake was 6:58 in Sri Lankan time, so that the tsunami reach the west coast of Sri Lanka two and a half hours after the generation. However, the second or third tsunami wave were reported to be the maximum at many places, for instance testified arrival time was 10:30 at the Kahawa district, 11:05 at the Moratuwa district. We can say that the second wave is surely larger than the first wave and the duration time, the wave period, was estimated to be 30 minutes or more.

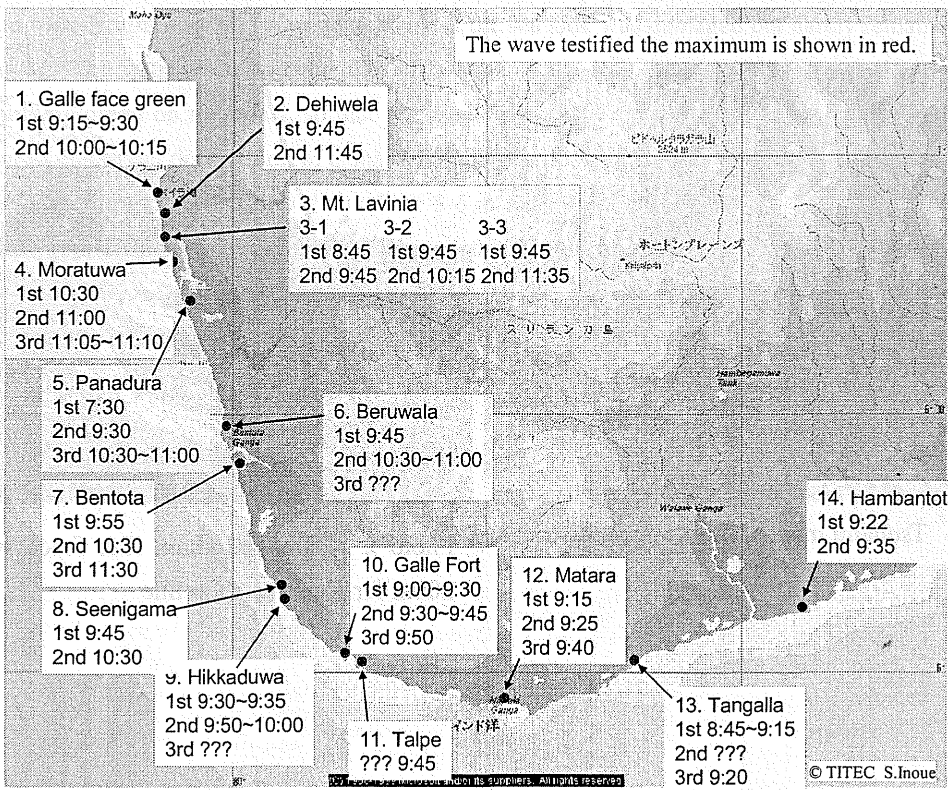


Fig. 2 Estimated arrival time of tsunami and the attacks (including the report by Inoue, TITEC)

3.2.3 Overview of the tsunami damage

There are a lot of houses made of bricks with plaster wall and wooden houses along the coast. Most of the damaged houses were classified into these kinds of structure. On the other hand, the damage on the structure made of a concrete seems to be slight. The detail discussion on the damage of the houses should be necessary with the information of the structure, location and angles of them and inundation, number of attacks and direction of tsunamis. The following are the summary of the field investigation at the main areas in this survey.

a) Koggala:

Koggala where the airport is located is placed 10km in east of Galle. And its averaged altitude is only 3.6m and the distance from the beach is 100m, where many trees were damaged by seawater. The measured heights are about 9 m as shown in Photo 1. Because the flat land continues inland, the inundation area was so large. The tsunami trace of 15cm height was found on the exterior wall of the house located 300m from the shoreline. The chain link fence that existed in the distance of 200m from the shore was crushed as shown in Photo 2, suggesting powerful wave force acting on the wall..

Photo 1 Tsunami trace at the Koggala district

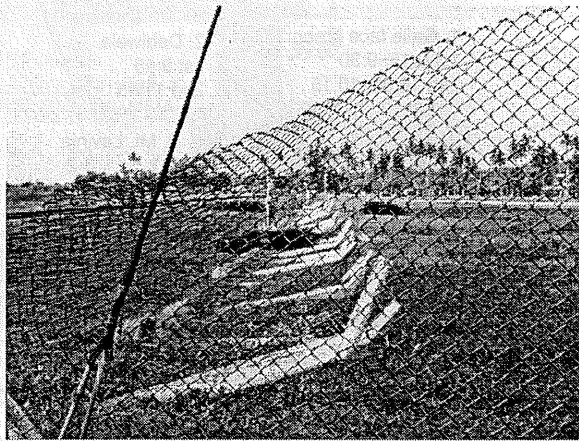
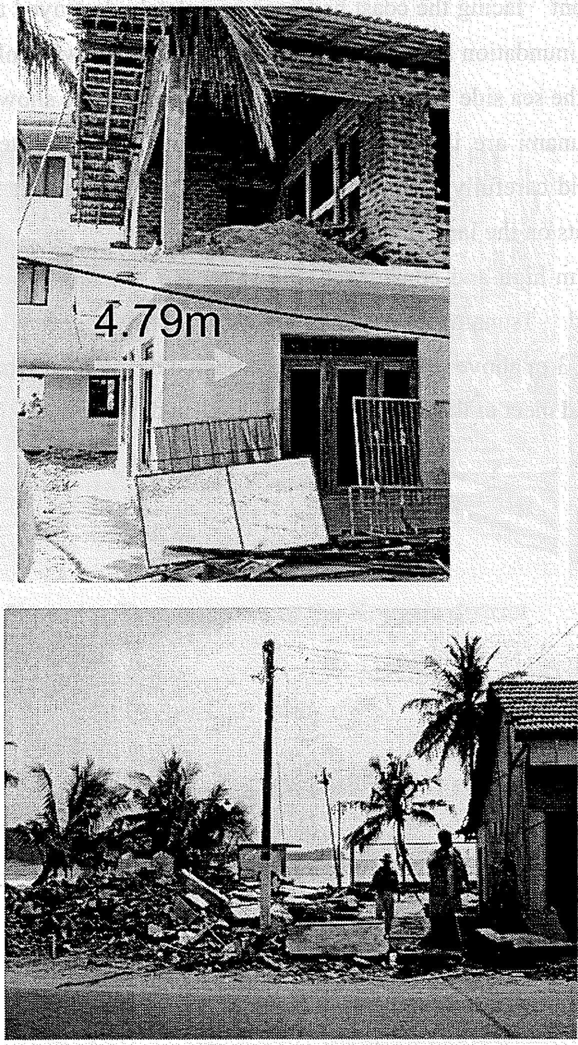


Photo 2 Damaged chain link fence which is 200m far from the shoreline

b) Coasts around Galle:

In the coastal area, there are two types of houses where the heights of tsunami traces on the walls were different. For the first house, the tsunami inundation height on the ground was largely 2.6m and the trace heights were 4.8 m, where the brick house at the front facing the coast had been completely destroyed as shown in Photo 3. On the other hand, the tsunami inundation heights on the second typed house was only 0.6 m and trace height was 3.2 m, where a house at the sea side was damaged but barely remained as shown in Photo 4. The inundation/trace heights of a tsunami are influenced by the situation such as existed house/building/green on the coast, so that we should carefully report this after the investigation and it is important to obtain the distribution of tsunami heights on the land in order to look at the effects.

In the Galle Fort surrounded by the wall of 5-6 m high and constructed 400 years ago, the inundation area is small, where the buildings were not damaged. Tsunami flood power was reduced by the seawalls. By contrast, a new central area in Galle is located 2-3 m above the sea level at the behind of the Fort. This is reported that he tsunami separated at the Fort could meet at the central area and inundated inland.



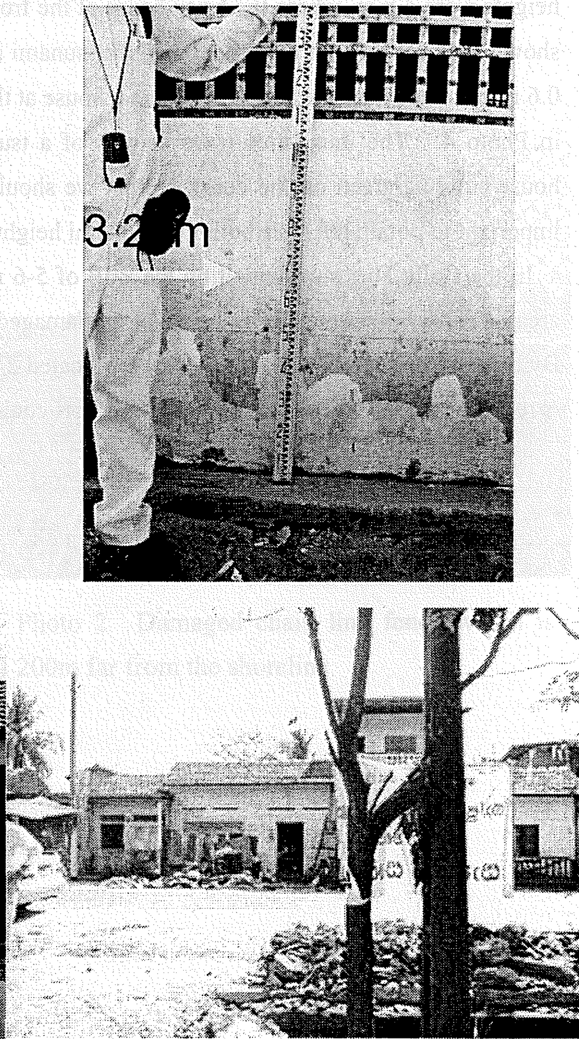


Photo 3 Tsunami inundation level(upper) and destroyed beachfront house (lower)

Photo 4 Tsunami inundation level(upper) and barely damaged beachfront house (lower)

c) Galle Port:

The tsunami traces were found on the wall of the storage shed and of the office building that are located at the entrance of the inland. The trace height from the mean sea level was 5m and 6m respectively. Though big destruction was not seen on the breakwater, the quay was destroyed as shown in Photo 5 and the services at the port was not available when we visited after the tsunami attack. The huge dredger ship was moved on the quay as shown in Photo 6.

Photo 5 Damage of the quay at the Galle Port

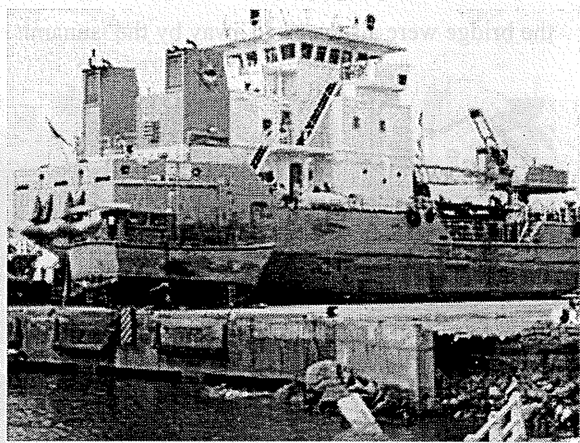


Photo 6 Lifted dredger ship on the quay

d) Dodanduwa:

In Dodanduwa which is 12 km in north of Galle. There is bridge constructed at the river mouth, which is made of concrete and seemed to have been built recently. The concrete handrail of the bridge, which thickness is about 20cm had broken and the height was 3.9m, was partially damaged as shown in Photo 7. It is explained from the situation that a broken fishing boat as shown in Photo 8 has been scattered that drifting debris collided. The people at this village told us that some of them were washed away by the tsunami flood though they evacuated through the bridge. Two persons who had taken the motorcycle on the bridge were also washed away by the tsunami.

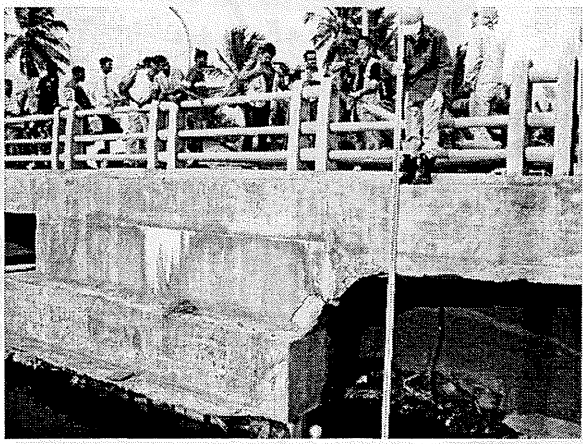


Photo 7 Damaged concrete handrail of the

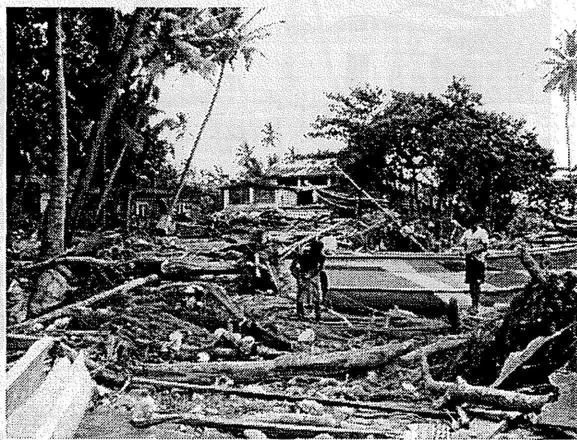


Photo 8 Broken fishing boats at Dodanduwa

e) Kahawa:

Details are described in section 3.4.

f) Ambalangoda:

In Ambalangoda which is about 80km in south of Colombo, the tsunami trace was found at 4.7m high on the exterior wall inside of the inundated house. The erosion prevention countermeasure has been taken along the coast with the rubble stones of about 500kg in weight as shown in Photo 9. It seems that the houses in seafront were not destroyed because of the rubble revetments. However, the foundation of the railroad line in the inland behind the village was severely scoured by the tsunami that propagated into the river, as shown in Photo 10. It is suggested that the horizontal vortex formed after passing the river mouth would cause the severe erosion.

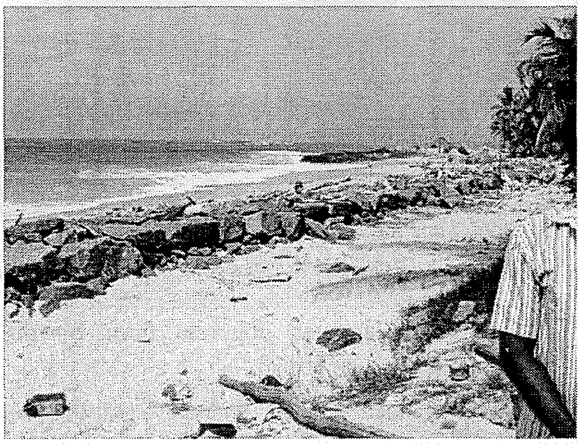


Photo 9 Erosion prevention countermeasure with rubble stones

Photo 10 Scouring damage on the foundation of railway at Ambalangoda

g) Beruwala Fishery Harbour:

At the Beruwala district which is located 53km in south of Colombo, the tsunami trace height outside the fishery harbor. exceeds 4 m, though it was only 2.3m from the sea. The houses had not been destroyed behind the fishing port as shown in Photo 11, it is thought that the tsunami power was reduced by the breakwaters at the harbor A lot of fishing boats were washed away from the harbor by the tsunami back current, and were drifted by the following tsunami attack to the northern coast as shown in Photo 12.

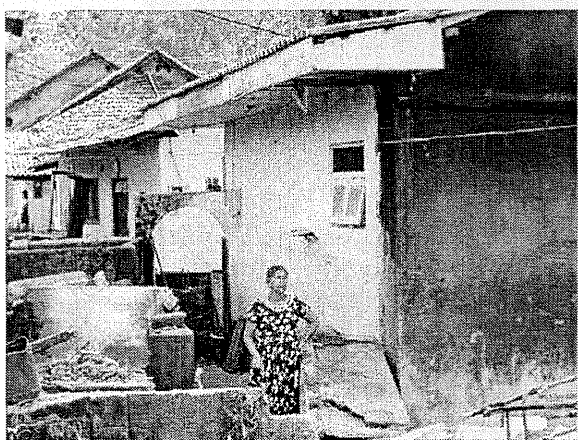


Photo 11 Barley damaged houses behind the Beruwala fishing harbour

Photo 12 Drifted fishing boats at the north coast of Beruwala fishing harbour

h) Paiyagala:

In Paiyagala which is 48km in north of Kahawa, there is a tsunami trace which is about 6m above the mean sea level, it is 4.2m far from the shore in the inundation level. Only a part of house such as windows and doors in the houses made of concrete were damaged as shown in Photo 13.

Photo 13 Barley damaged building made of concrete

Photo 14 Damaged concrete floor by the tsunami lift force

i) Panadura:

The Panadura district 25km in south of Colombo is located between the river and the sea. It is indicated that the damage was caused by both of the tsunami runing up the river and the overtopped tsunami from the coast. The impact of tsunami, especially lift force, was able to destroy the concrete floor and roof as shown in Photo 14.

3.3 Discussion

3.3.1 Train Damaged at Kahawa

At Kahawa, a nine-car train was damaged, killing about 1,500 of its passengers. This train happened to have stopped while passing this point when the first wave of the tsunami struck. The first wave submerged the land to a depth of about 1m, not causing any damage. The land along the shoreline is a little lower than the coast road (Fig. 3), so water brought by the first wave was retained there.

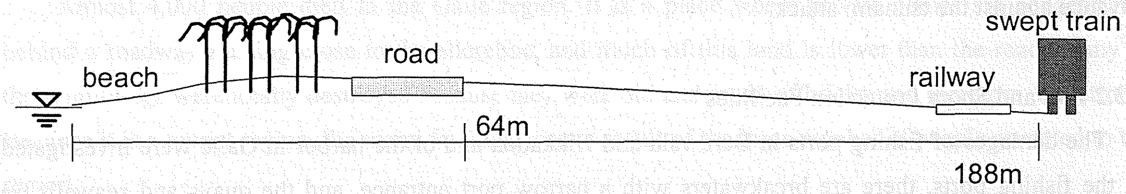


Fig. 3 Cross section of the damaged area, Kahawa, where the train was washed away

The residents of the district saw the disaster and began to flee inland. Some of them escaped into the stopped train. Generally railway cars are stronger and higher than automobiles etc., the residents probably thought they were safe. This would be why not only passengers but also residents were died in the train cars. But the second wave that struck 30 to 40 minutes layer, about 15 minutes according to other witnesses, engulfed the train shown in Photo 15.

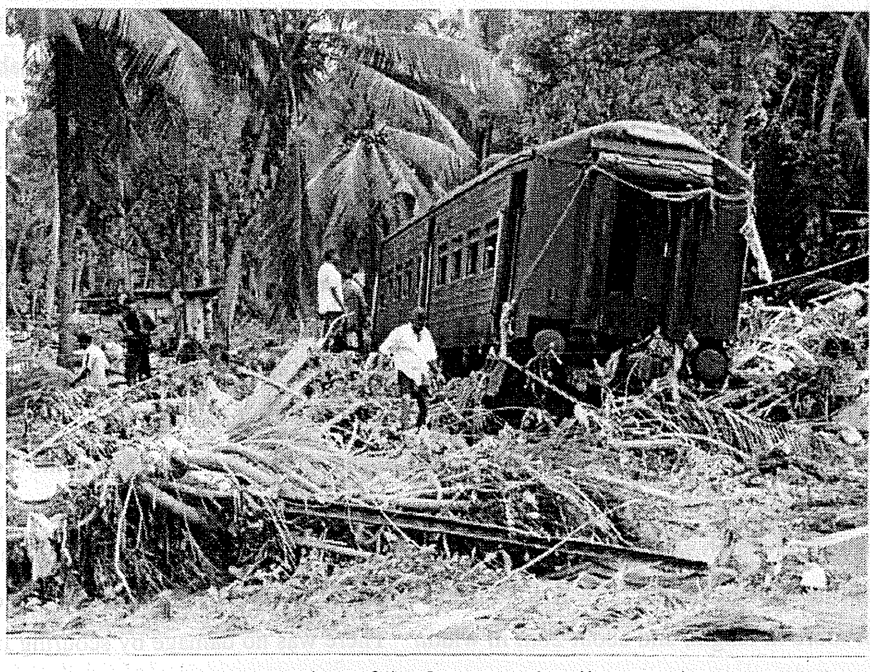


Photo 15. View of the Overturned Railway Train

The traces of the second tsunami revealed submersion depth of about 5 m, and locally up to 10 m. The railway cars were not severely damaged, but were filled with sea water that drowned almost all the passengers and residents who could not escape from inside. It is a tragedy caused by the tsunami that struck in an instant. People started to evacuate after the first tsunami, but lost their lives by fleeing to a dangerous place, which is inside of the train. Actually, there is school building left about 50m from the railway, which is survived after the tsunami attack. It was important to evacuate to such a building. When a tsunami strikes, in principle, people should evacuate to a high refuge instead of a place far from the shoreline. In a district where flat ground spreads inland, a usable evacuation site such as a school or building must be prepared in advance against the tsunami attack.

3.3.2 Port and Shore Protection Facilities

The damages of fishing ports in Beruwala and Hikkadua and of the harbor in Galle were investigated. In the fishing ports, there are breakwaters with a narrow port entrance, and the quays and seawalls are constructed, which would contribute to the damage reduction. Therefore, there was the difference about the tsunami inundation height between the inside and outside the port. However, the breakwater was not transformed itself but damaged some, and the many fishing boats were washed away from the harbor and were stranded.

In this case, heights of the rubble revetment was not high enough to protect the area against the tsunami flood by dissipating the energy. The rubble revetment was destroyed along the coast and heavy rubble stones were moved ten-odd meters at the place where the flood velocity of the tsunami could be large.

At the Galle Port, the height of tsunami trace was about 5 m, and there were damage on the quay, the scouring of the quay foundation by undertow, the lifted large-scale work ship and the inundated harbors buildings in the first floor. The function and services at the harbor stops though fishing port and harbors has not been damaged with catastrophic. And the influence and impact on not only the rehabilitation and reconstruction but also the local society become significant.

3.3.3 Sediment Displacement

A large-scale scouring or sedimentation was found around the building in the coastal area, at the foot of the bridge pier, and around the steel tower. Even though there was no damage on the superstructures, most buildings were declined by the scouring on the foundation and lost the function. Such a sand transportation is caused by not only the runup but also the undertow and current. The large-scale scouring was caused by a strong flow of one direction continuing for long period time.

A lot of scouring at the root of vegetation were also seen in the coast. Sand was moved off by the impulsive force and the undertow of tsunami. In addition, tsunami runup to a narrow river mouth and spread at a large river, which would generate a large vortex. There is an example of this situation, and it caused the scouring damage on the railway foundation as shown in Photo 10. Scouring scale was 2m in depth, 200m or more in length, and about 20m in width. There was no damage by scouring if the ground is coated with asphalt or concrete.

3.3.4 Human Suffering

In the southwest part of Sri Lanka where this survey was done, there are places where the land resembles reservoirs and where it slopes gently downward. The severity of the human loss was increased because there are few tall buildings or other evacuation sites at this region. And the people of Sri Lanka know nothing about tsunami, having never had any experience of this phenomenon. No ground quake, no tsunami information and no safety area against tsunamis are one of the main reasons why the casualties exceed 40,000 in Sri Lanka. Table 2 Shows the number of deaths, injured, missing and displaced people in each area.

Almost 4,000 people died in the Galle region. It is a place where private homes are concentrated behind a roadway running close to the shoreline, and much of this land is lower than the road. Many of these buildings were totally destroyed because they were old and made of bricks, and therefore, not strong. Because it is a tourist region, the many fatalities were a result of the large number of people attracted to the region.

Table 2 Human damage in Sri Lanka as of February 2005

District,	Deaths	Injured	Missing	Displaced
Colombo	76		12	16,139
Gampaha	7			32,000
Kalutara	213	421	48	37,595
Galle	4,101	2,500		120,000
Matara,	1,205	8,288	404	41,900
Hambantota	4,500			27,351
Ampara	10,436	120		183,527
Mullaitivu	3,000	2,500	1,300	24,557
Batticaloa	2,497	1,166	1,097	203,807
Trincomalee	957		335	51,863
Killinochchi	560	147	56	49,129
Jaffna	2,640	541	540	48,729
Puttlam	4			850
Vavuniya				641
Total	30,196	15,683	3,792	838,088

3.4 Summary

The detailed height of tsunami traces and state of tsunami damage caused by the Sumatra Offshore Earthquake Tsunami in southwest Sri Lanka were studied. The study revealed that the average tsunami height was about 5 m, and that the highest tsunami was the second tsunami that arrived about 30 minutes after the first tsunami.

The principal damage caused by the tsunami were (1) inundation of the land far inland on flat low coastline land, (2) total destruction of most wooden and brick buildings and partial destruction of buildings made of concrete, (3) ships washed out to sea or grounded on the land, and (4) superstructures damaged by scouring of the quay walls and ground. It was confirmed that breakwaters and similar port and harbor structures reduced the tsunami.

We wish to express our gratitude to Ichizono Toshiro (councilor and manager of the Colombo office) of Japan Port Consultants Ltd. and to Tatsumi Masahiro (Director of the Sri Lanka office) of Wakachiku Construction for their assistance with this survey. We also appreciate for collaboration to exchange the information and data with the experts in Sri Lanka; Prof.Samantha Hettiarachchi Coastal Engineering and Management University of Moratuwa, Dr.Saman Smarawickrama Coastal Engineering and Management University of Moratuwa, Dr.Nimal Wijayaratna Senior Lecturer, University of Ruhuna,

This study was carried out as part of Overall Clarification of Tsunami Damage by the Sumatra Offshore Earthquake that is an emergency disaster survey financed by a science and technology research subsidy. In conclusion, we offer our prayers for the souls of the victims of this terrible disaster.

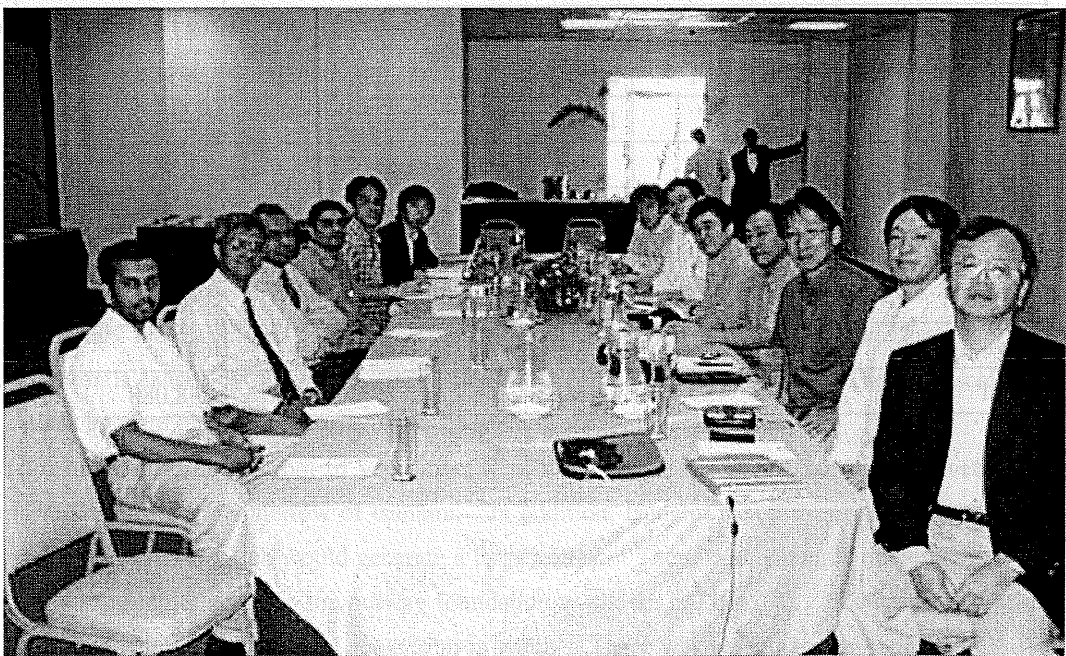


Photo 16 Meeting after the field survey to report the results and to exchange the information on the tsunami by the participation of experts from Sri Lanka and Japan

Chapter 4 Field Survey and Numerical Simulation on the 2004 Off Sumatra Earthquake Tsunami in Thailand

4.1 Introduction

On December 26, 2004 at 07:59 am (UTC 00:59 am, JST 09:59 am), a giant earthquake was occurred off the west coast of northern Sumatra, Indonesia. Its epicenter is shown in Figs. 4.1 and 4.2 shows that the seismic activity in this region has been very high as the Pacific Rim.

Its magnitude had been reported by some institutes as shown in Table 4.1. The West Coast Alaska Tsunami Warning Center and the Pacific Tsunami Warning Center issued 8.0 within fifteen minutes after the earthquake. The magnitude 9.0 which is well-known nowadays were reported nineteen hours later. These revised magnitudes, however, don't mean their failures, but indicate difficulty to analyze such a giant earthquake in a moment by the leading seismologists even. This is the fourth largest earthquake in the world since 1900 as shown in Fig. 4.3 and Table 4.2. An another earthquake which was occurred in this region three months later is also the seventh largest event.

The giant earthquake generated a huge tsunami which is the third largest event since 1900 as shown Table 4.3. This tsunami attacked many countries in the Indian Ocean. In the extremely large areas except Indonesia, Andaman Islands and Nicobar Islands shown in Fig. 4.4, the tsunami exclusively caused their extensive damages. This is the greatest tsunami disaster in history.

The tsunami attacked the southeast coast of Thailand where is about 500 km far from the epicenter. Because the area has worldwide resorts like Phuket Island and the tsunami arrived at the coast around a high tide shown in Fig. 4.5, a fearful disaster happened there. 5,400 people were killed and 3,100 people are missing due to the tsunami in Thailand. To study this disaster, a field survey was carried out from December 30, 2004 to January 3, 2005 in the southeast coast of Thailand. Further, a numerical simulation has been conducted to investigate the source mechanism of the tsunami. In this chapter, those results are reported.

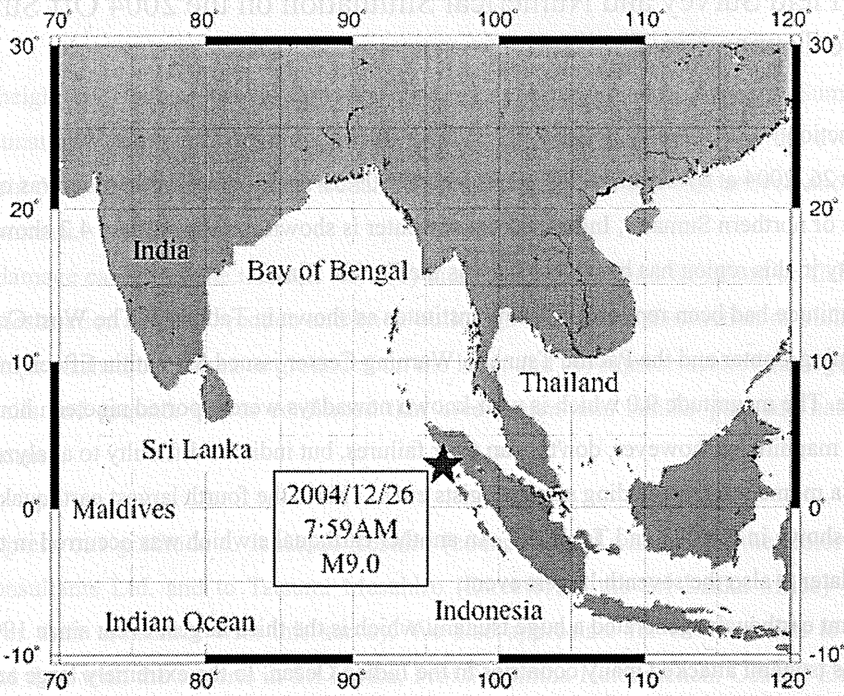


Fig. 4.1 The epicenter of 2004 Sumatra Earthquake

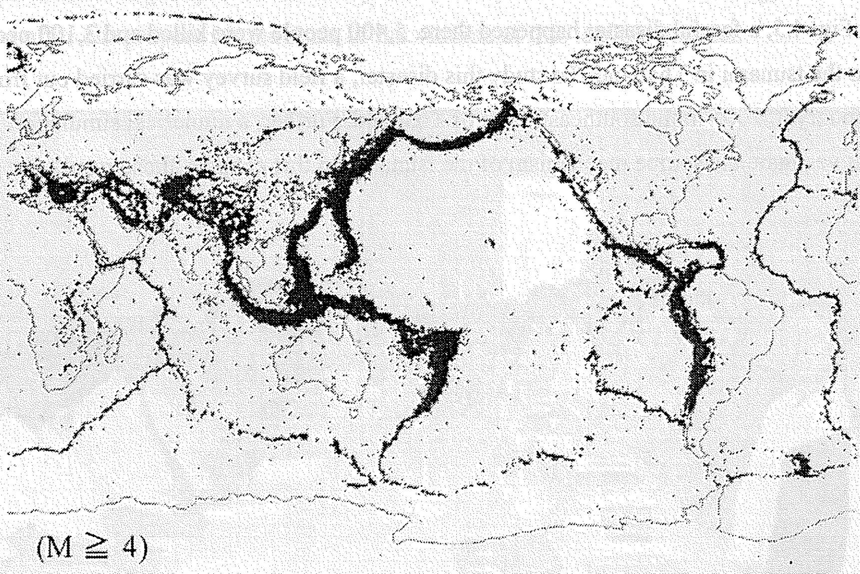


Fig. 4.2 Seismic activity in the world from 1978 to 2000 (Utsu, 2001)

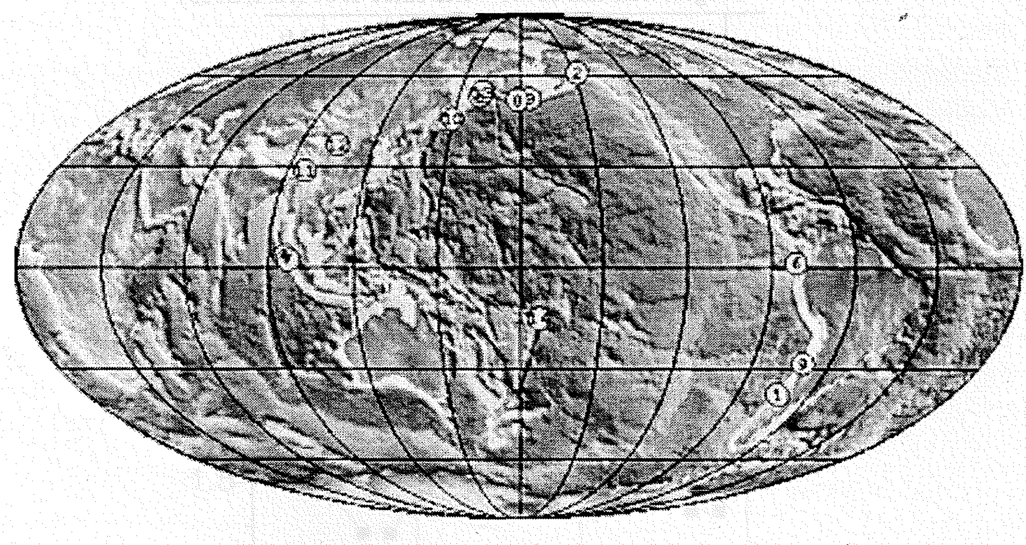
Table 4.1 A history of reported magnitude of the earthquake

Institute	Magnitude *1	Issued time (UTC) *2	Time after the event *3
WCATWC	M 8.0	12/26/2004 01:14	00:15
PTWC	M 8.0	12/26/2004 01:14	00:15
PTWC	M 8.5	12/26/2004 02:04	01:05
WCATWC	M 8.5	12/26/2004 02:09	01:10
USGS	M 8.5	12/26/2004 02:17	01:18
USGS	Mw 8.2	12/26/2004 02:23	01:24
Harvard Univ.	Mw 8.9	12/26/2004 05:26	04:27
Harvard Univ.	Mw 9.0	12/26/2004 20:02	19:03
WCATWC	M 9.0	12/27/2004 15:34	36:35
PTWC	M 9.0	12/27/2004 15:35	36:36

*1 "M" means that a type of magnitude was not shown in the e-mail.

*2 In the case of no issued time shown in the e-mail, the posted time informed by the institute's SMTP server is used.

*3The origin time of the earthquake is assumed as 12/26/2004 00:59 UTC by USGS.



USGS National Earthquake Information Center

Fig. 4.3 Largest earthquakes in the world since 1900 (USGS, 2005)

Table 4.2 Largest earthquakes in the world since 1900 (USGS, 2005)

	Location	Date UTC	Magnitude	Coordinates	
1	Chile	1960 05 22	9.5	38.24 S	73.05 W
2	Prince William Sound, Alaska	1964 03 28	9.2	61.02 N	147.65 W
3	Andreanof Islands, Alaska	1957 03 09	9.1	51.56 N	175.39 W
4	Off the West Coast of Northern Sumatra	2004 12 26	9.0	3.30 N	95.78 E
5	Kamchatka	1952 11 04	9.0	52.76 N	160.06 E
6	Off the Coast of Ecuador	1906 01 31	8.8	1.0 N	81.5 W
7	Northern Sumatra, Indonesia	2005 03 28	8.7	2.08 N	97.01 E
7	Northern Sumatra, Indonesia	2005 03 28	8.7	2.08 N	97.01 E
13	Kamchatka	1923 02 03	8.5	54.0 N	161.0 E
14	Tonga	1917 06 26	8.5	15.0 S	173.0 W

Table 4.3 Largest tsunamis in the world since 1900 (Abe, 2005)

	Earthquake	Date UTC	Mt
1	Chile	1960 05 22	9.4
2	Aleutians	1946 04 01	9.3
3	Sumatra, Indonesia	2004 12 26	9.1
4	Alaska	1964 03 28	9.1
5	Kamchatka	1952 11 04	9.0
5	Aleutians	1957 03 09	9.0

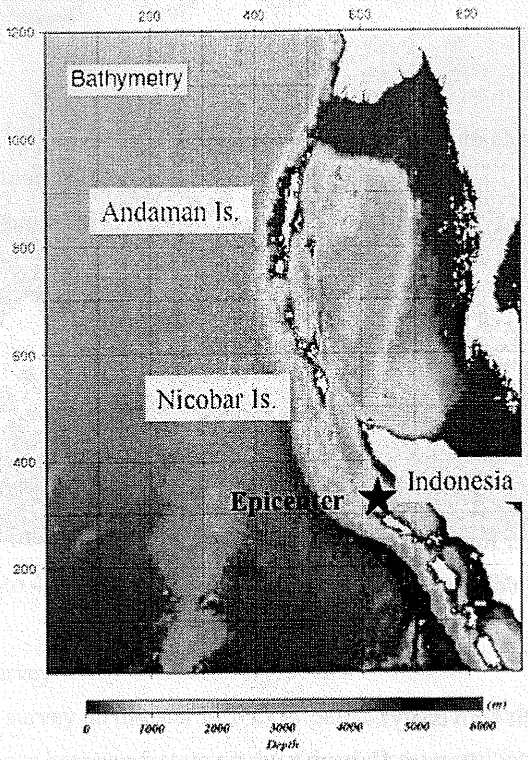


Fig. 4.4 Bathymetry

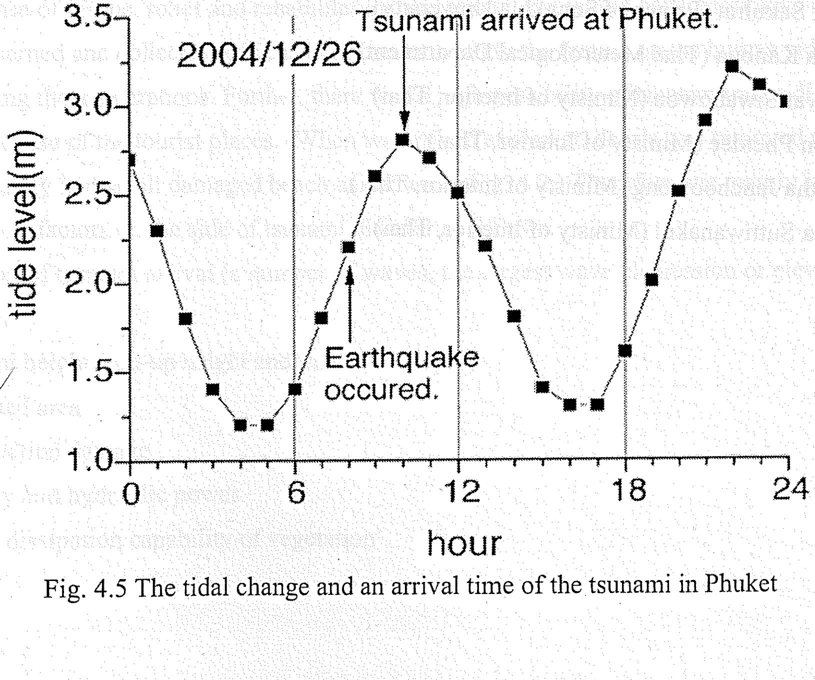


Fig. 4.5 The tidal change and an arrival time of the tsunami in Phuket

4.2 Field Survey

4.2.1 Period and Team Members of Field Survey

Our field survey team consisted of the following members and the survey had been conducted from December 30, 2004 to January 3, 2005. In the afternoon of January 3, we hold a press conference and reported the preliminary results of our field survey by the Thailand government request.

[JAPAN]

Hideo Matsutomi (Akita University) Reader of survey team
Tomoyuki Takahashi (Akita University)
Tetsuya Hiraishi (Port and Airport Research Institute)
Masafumi Matsuyama (Central Research Institute of Electric Power Industry)
Kenji Harada (Disaster Reduction and Human Renovation Institution)
Sittichai Nakusakul (Yokohama National University)

[THAILAND]

Seree Supartid (Ransit University)
Mongkonkorn Srivichai (Rangsit University)
Suchart Limkatanyu (Prince of Songkhla University)
Danupon Tonnayopas (Prince of Songkhla University)
Pruittikorn Smithmaitrie (Prince of Songkhla University)
Jareerat Sakulrat (Prince of Songkhla University)
Wattana Kanbua (Thai Meterological Department)
Chaitawat Siwabowon (Ministy of Interior, Thai)
Sittiporn Phetdee (Ministy of Interior, Thai)
Warlsatha Janchoowong (Ministy of Interior, Thai)
Suchaya Suttiwanakul (Ministy of Interior, Thai)

Photo 4.1 Press conference on the field survey in Phuket

4.2.2 Objective of Field Survey

The general objective of field survey on disaster is to clear damages and to study their factors. A magnitude of damage is a result of a balance between factors on the side of disaster and factors on the human side. In tsunami disasters, the former factors imply tsunami height, velocity, hydraulic power, etc. and the latter factors imply preparedness, countermeasure, education, evacuation, etc. Many field surveys are desired to investigate factors on both sides. Our field survey, however, was carried out just 4 days after the disaster, and it was a phase of rescue, relief and rehabilitation operations. We would need interviews with the authorities concerned and collecting official documents to study the factors on the human side, but we were afraid of retarding those operations. Further, there was a high possibility of tsunami traces disappearing immediately because of the tourist places. (When we arrived at phuket, debris was removed and business was opened actually in a small damaged beach as shown in Fig. 4.2.) Therefore, we mainly investigated damages and their factors on the side of tsunami disaster as follows.

- Situation of tsunami arrival (a number of waves, the largest wave, depression or elevation of the leading wave, etc.)
- Tsunami height (run-up height and inundated depth)
- Inundated area
- Construction damage
- Velocity and hydraulic power
- Energy dissipation capability of vegetation

Photo 4.2 A small damaged beach in Phuket opened a business on Dec. 30, four days after the disaster

4.2.3 Field Surveyed Region

Our field survey was conducted in the southwest coast of Thailand shown in Fig. 4.6. There are Khao Lak, Phuket Island and Phi Phi Islands. The investigated coastline was about 140 km long.

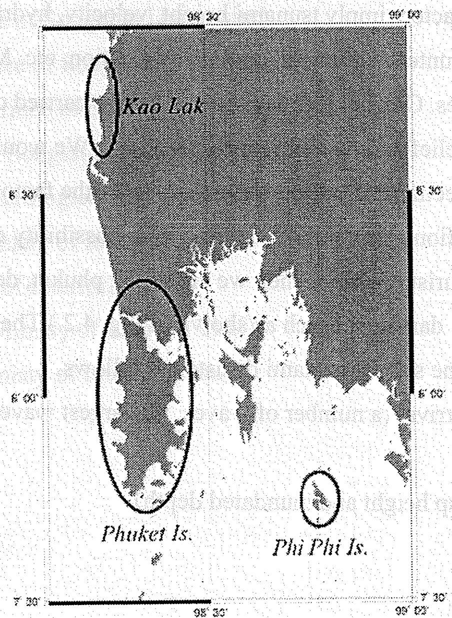


Fig. 4.6 Field survey region

4.2.4 Implement of Field Survey

We made two or three survey groups, and investigated in the north and the south regions respectively. As transportations in the field, rented cars were used in Khao Lak and Phuket Island, and a high-speed boat provided by the Port Authority of Thailand is used to Phi Phi Islands.

We carried out the measurement of tsunami traces and the hearing on residents as shown in Figs. 4.3 and 4.4. As the tsunami traces, driftage and debris, inundated lines on wall, withered plants, etc. were probed as shown in Fig. 4.7. We took not only one trace but some traces to comprehend the typical tsunami height in the region. When a height of the trace was low, we confirmed it by hearings on residents. For the accurate measurement of tsunami height and distance from shore, we used the Laser Distancemeter and the optic prism.

Because of the different tide levels when the tsunami arrived and the measurement was carried out, the measured tsunami heights were corrected by the method as shown in Fig. 4.8. The tsunami arrival times are assumed uniformly as at 10:00 am in local time.

Photo 4.3 The measurement on tsunami height with the laser distance meter

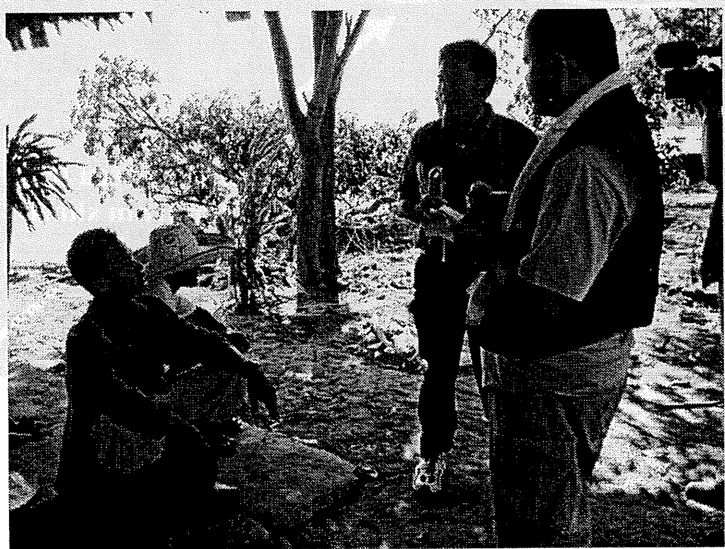
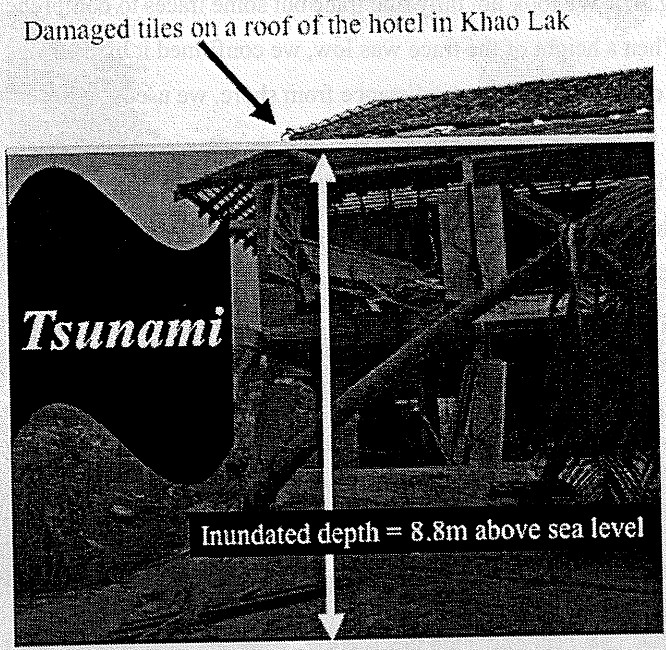
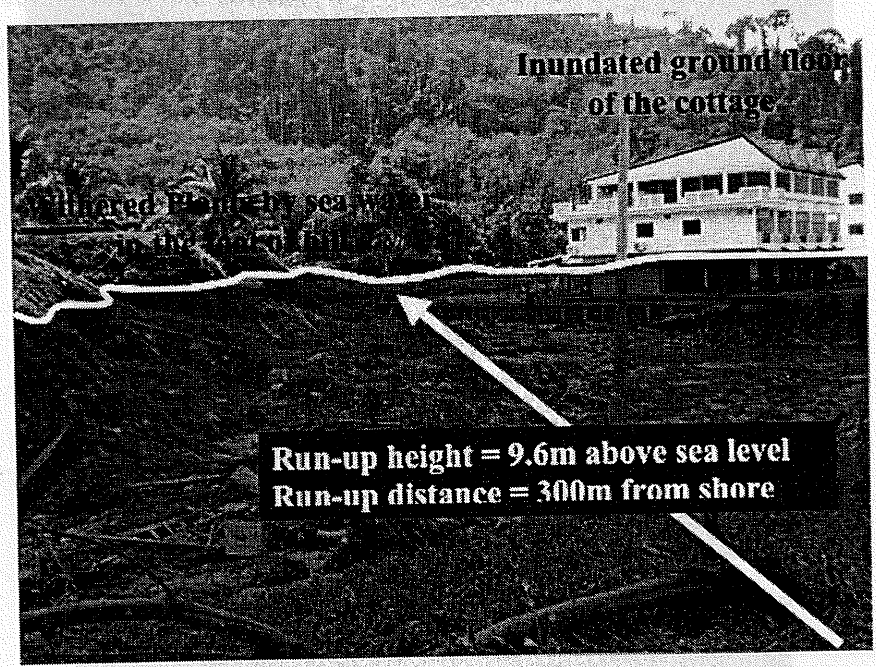


Photo 4.4 A hearing on the resident



(a) A case of inundated depth



(b) A case of run-up on height and distance from shore

Fig. 4.7 Examples of tsunami trace discrimination

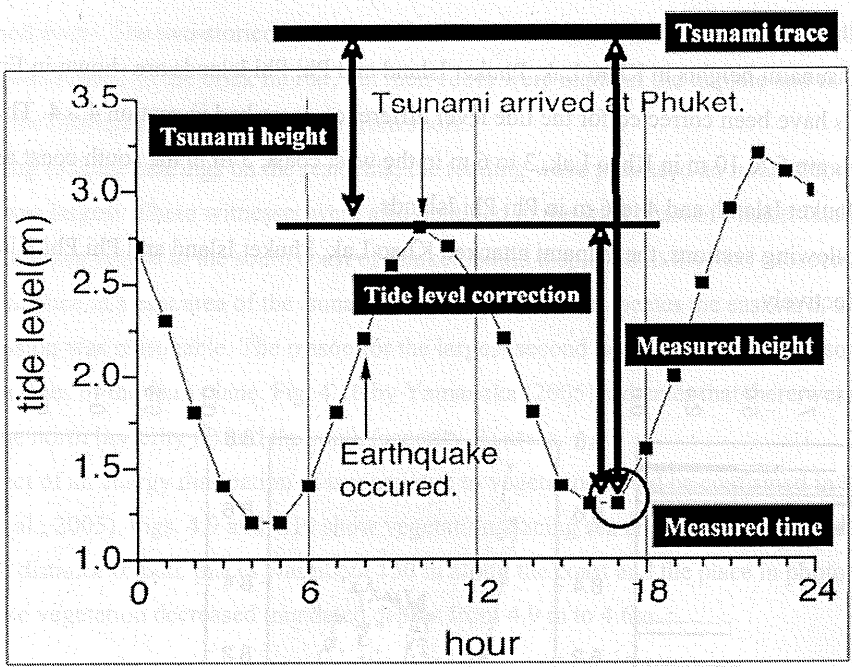


Fig. 4.8 The method of tide level correction

4.2.5 Results of Field Survey

The measured tsunami heights in Khao Lak, Phuket Island and Phi Phi Islands are shown in Fig. 4.9. These tsunami heights have been corrected for the tide level difference described in section 4.2.4. The typical tsunami heights are 6 to 10 m in Khao Lak, 3 to 6 m in the west coast, 3 m in the south coast and 2 m in the east coast of Phuket Island, and 4 to 6 m in Phi Phi Islands.

In the following sections, the tsunami attacked Khao Lak, Phuket Island and Phi Phi Islands are examined respectively.

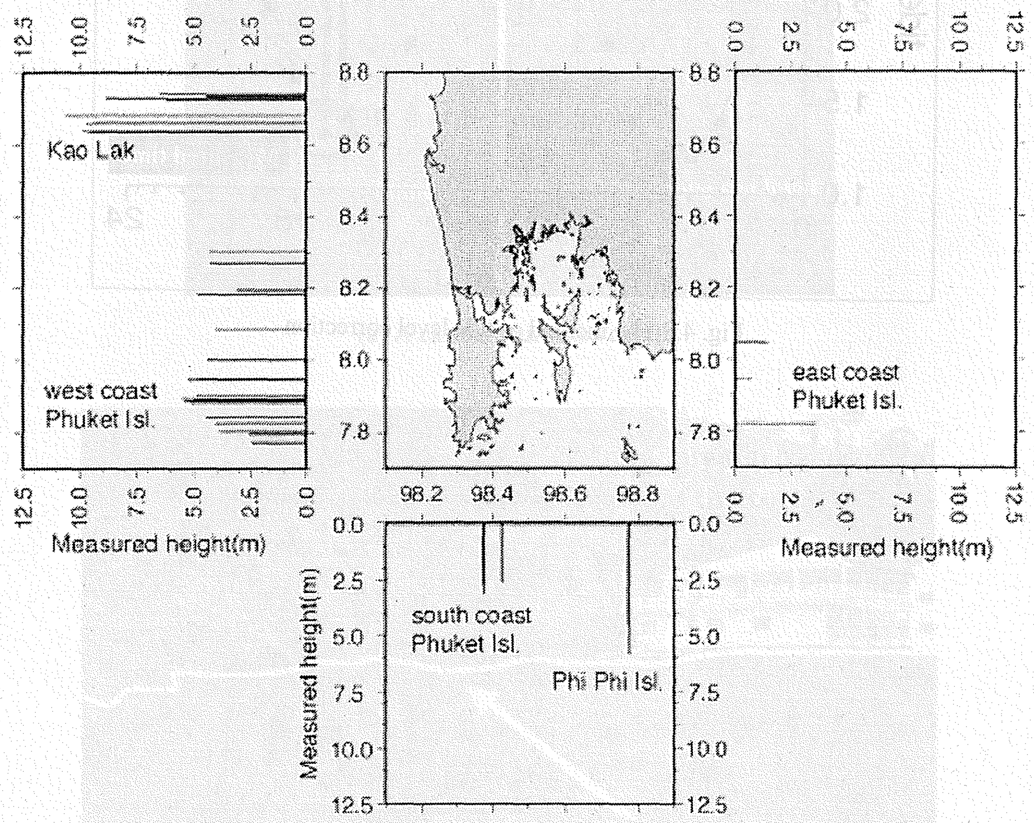


Fig. 4.9 Measured tsunami heights

(1) Khao Lak

The largest tsunami in Thailand attacked this area. Some tsunami heights were further than 10 m and the inundated depths was 4 to 7 m in the south of Khao Lak. Photo 4.5 shows that the tsunami inundated the third floor of a hotel. The tsunami heights in Khao Lak were much higher than Phuket Island. The reason for this difference seems to be an effect of local bathymetry off Khao Lak (Suzuka, 2005) and a generation of the soliton fission. Some photos and video tapes suggested there was the soliton fission. Photo 4.6 and 4.7, for examples, show two lines of the wave breaking at a short interval.

The velocities were 6 to 8 m/s and the drag forces were 3.8 to 6.7 tf/m^2 (3.7 to 6.6 x 10^4 Pa) in the inundated area estimated from the inundated depths in the south of Khao Lak (Matsutomi et al., 2005). This area was a new tourist place and there were many hotels and cottages. Those cottages and two-storied houses close to shore were totally damaged. In the mid-area of the inundation, their walls and pillars were partially flushed away. The two-storied houses consisted of floors and pillars made of the reinforced concrete, and walls made of the brick mortar, but their roofs were made of the tinplate and the brick. Photo 4.8 was taken the damages in the tourist place from shore.

According to some hearings on the residents, the reading wave produced an initial depression and the second wave was largest. These witnesses were also obtained in the west coast of Phuket Island and coincident with a tide record in the south coast of Phuket Island displayed in the next subsection. Because there was subsidence in a east area of the tsunami source and Thailand locates the eastward, the leading-depression was reasonable. The reason for the largest second wave seems to be a resonance effect and plural asperities of the fault plane. Fig. 4.10 by Yamanaka (2005) indicates that there were two large asperities in the north (asperity C) and the south (asperity B) areas.

The effect of an energy dissipation of tsunami due to vegetation could be confirmed in Khao Lak (Matsutomi et al., 2005). Figs. 4.9 and 4.10 show vegetations facing sea and houses at the back of the vegetations. A distance of both places was about 150 m along the coast and the place in photo 4.10 located the north. These vegetation decreased inundated depths from 4.9 m to 4.6m.

Photo 4.5 The tsunami inundated the third floor of a hotel (left building in photo) in Khao Lak

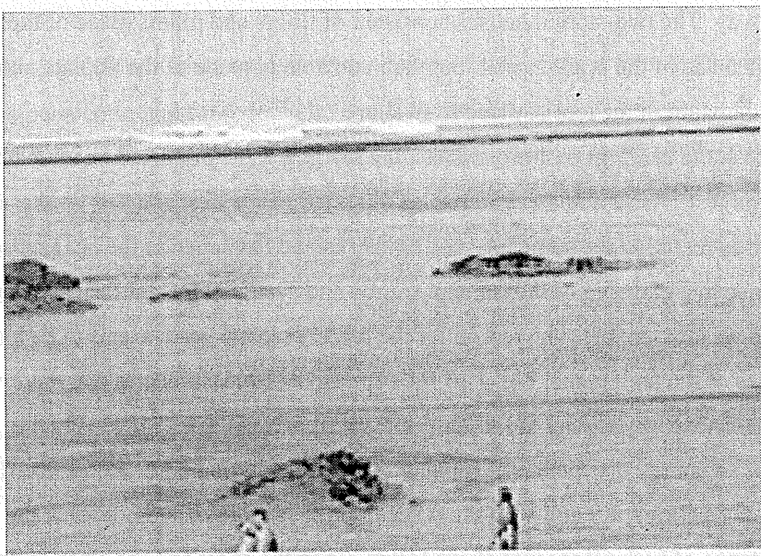


Photo 4.6 The tsunami attacked at Khao Lak (BBC, 2005)

Photo 4.7 The tsunami attacked at Khao Lak (Amateur Asian Tsunami video Footage, 2005)

Photo 4.8 The heavy damaged hotels in Khao Lak

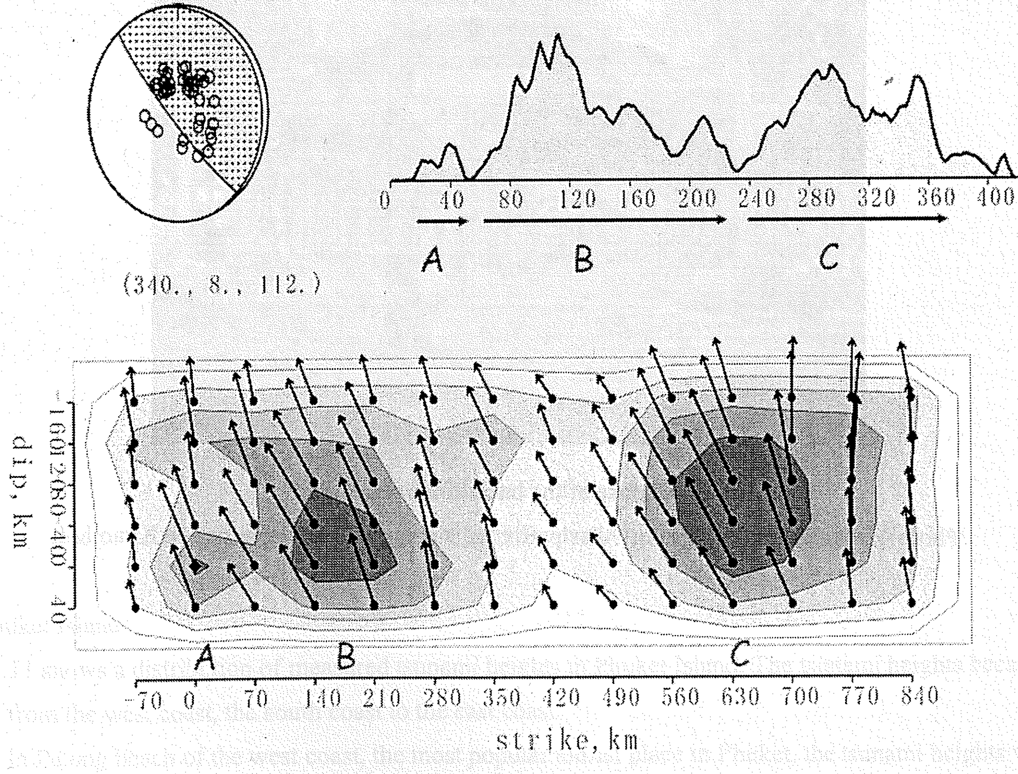
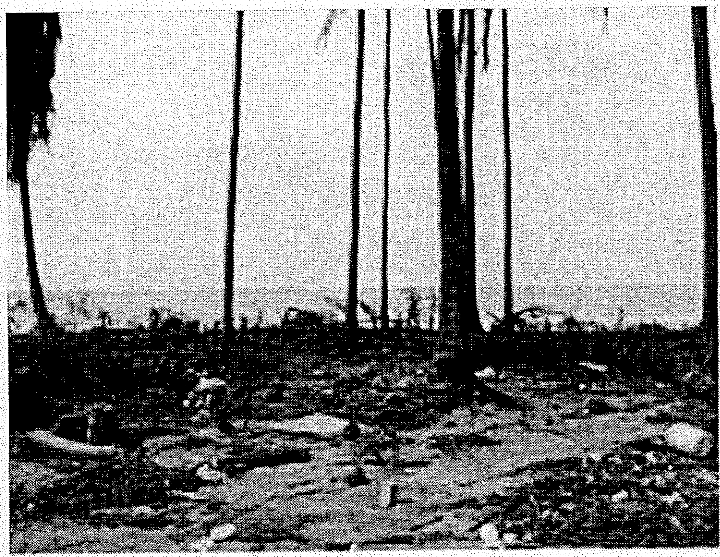
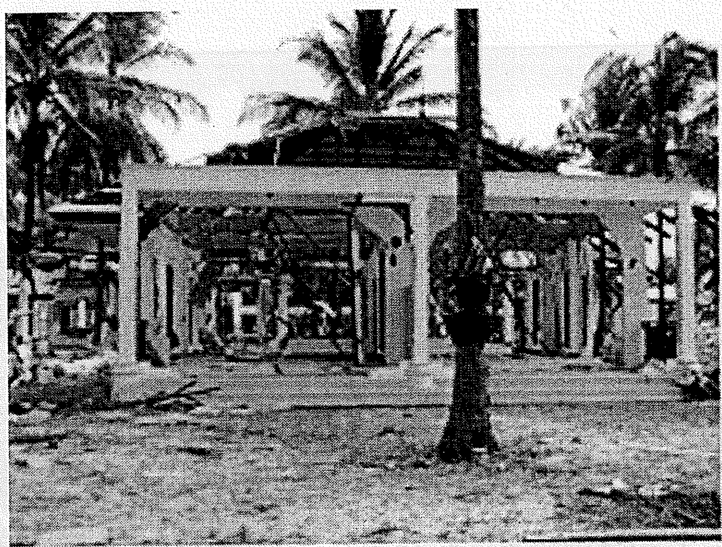


Fig. 4.10 Source rupture process of the earthquake (Yamanaka, 2005)



(a) A vegetation facing sea



(b) A house at the back of the vegetation

Photo 4.9 An example of energy dissipation of tsunami due to vegetation in Khao Lak

(a) A vegetation facing sea

(b) A house at the back of the vegetation

Photo 4.10 An example of energy dissipation of tsunami due to vegetation in Khao Lak

(2) Phuket Island

Fig. 4.11 shows a distribution of measured tsunami heights in Phuket Island. The tsunami heights became lower from the west coast, the south coast to the east coast.

In Patong beach of the west coast, the most popular tourist place in Phuket, the tsunami heights were 5 to 6 m and the inundated depths was about 2 m. The velocities were 3 to 4 m/s and the drag forces were 0.9 to 1.7 tf/m^2 (0.9 to 1.7 x 10^4 Pa) in the inundated area estimated from the inundated depths (Matsutomi et al., 2005). In the case of the inundated depth of about 2 m, Japanese wooden houses show "very heavy damage" as much as "substantial to heavy damage". In Patong beach, however, there were many houses built of brick and "substantial to heavy damage" was predominated as shown in Photo 4.11.

In Karon beach of the west coast, the coastal road which laid on the higher place than shore, acted as seawall and protected a hotel behind as shown in Photo 4.12. At the southern place in same Karon beach, there was not higher road and hotels were damaged.

In the east coast where is at the back of Phuket Island to the tsunami source, the tsunami height was about 2 m. In a river mouth, many boats were damaged as shown in Photo 4.13. Fortunately, concrete bridge piers had no damage. The tsunami propagated anticlockwise around Phuket Island as Okushiri Island in the 1993 Hokkaido Nansei-ok Earthquake Tsunami.

According to some hearings on the residents, the reading wave produced an initial depression and the second wave was largest. These phenomena agree with a tide record in the south coast of Phuket Island as shown in Fig. 4.12 and were examined in the former subsection.

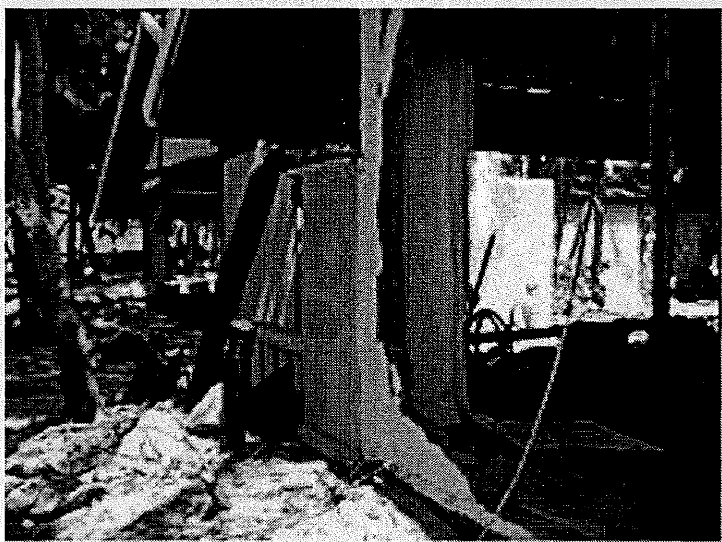


Photo 4.11 The broken wall of a house built of brick in Patong beach

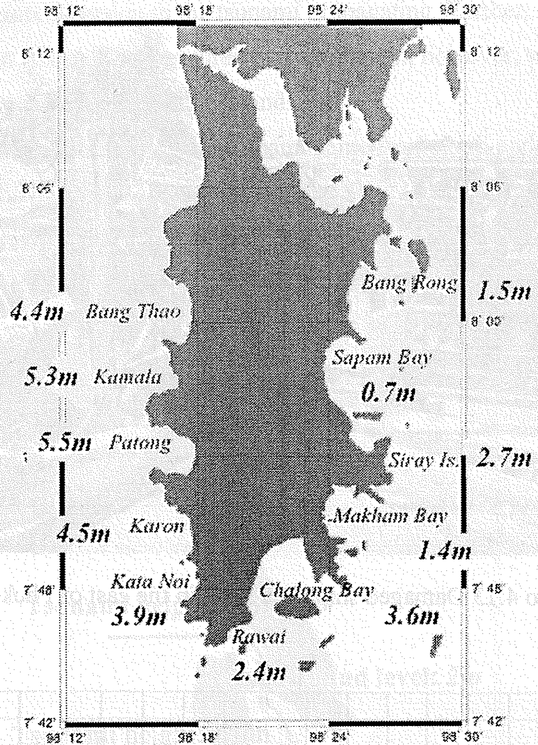


Fig. 4.11 Measured tsunami heights in Phuket Is.

Photo 4.12 The high road reduced the tsunami as seawall in the Karon Beach

Photo 4.13 Damaged ships in a river in the east of Phuket Is.

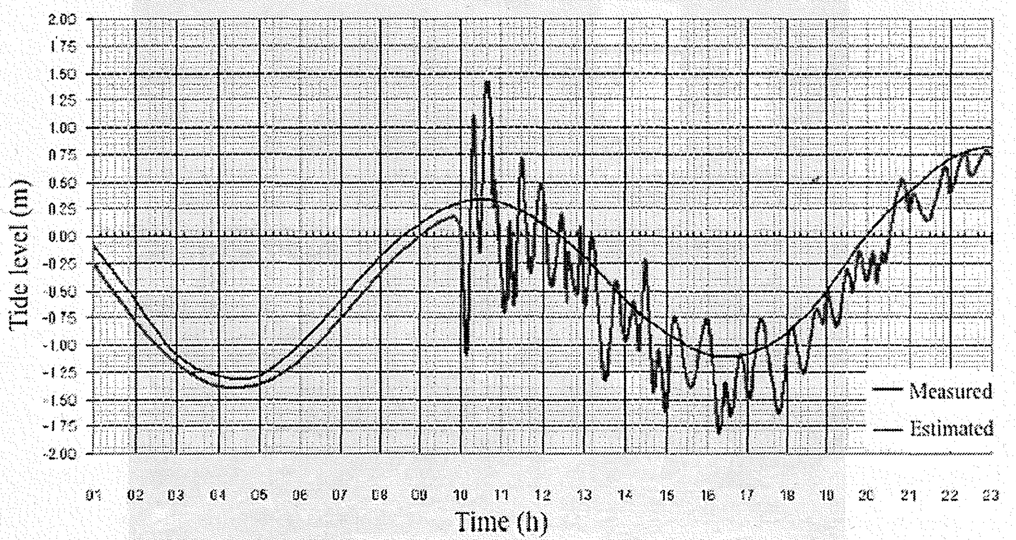


Fig. 4.12 Tide record in the south of Phuket

(3) Phi Phi Islands

Phi Phi Islands had a beautiful coral reef and were popular as scuba diving spots. The islands consist of Phi Phi Don Island and Phi Phi Le Island as shown in Fig. 4.13. The coast of Phi Phi Le Island is bluff and nobody had lived there. In Phi Phi Don Island, there were many hotels and cottages, thus the tsunami damage was occurred in this island.

A shape of Phi Phi Don Island is similar to "H" and there are two bays in the north coast and the south coast as shown in Photo 4.14. Photo 4.15 shows the north bay which is shallow and had a beautiful beach. Photo 4.16 shows the south bay which is deep and had a port.

The north bay is opened to the northwestward, thus it was faced to the tsunami coming direction. The measured tsunami height in this beach was 5.8 m. On the other hand, the south bay is opened to the southeastward. It was a opposite direction to the tsunami propagating. Further, Phi Phi Le Island locates to cover the port of Phi Phi Don Island. The measured tsunami height, however, was 4.6 m in this port. It indicated that the tsunami propagated around the islands.

According to some witnesses reported, the tsunami came from north and south, and totally flushed the central area away. The ground level was about 2 m above sea level, but there were many cottages and hotels. Therefore, the tsunami waves from north and south destroyed the area as shown in Photo 4.17.

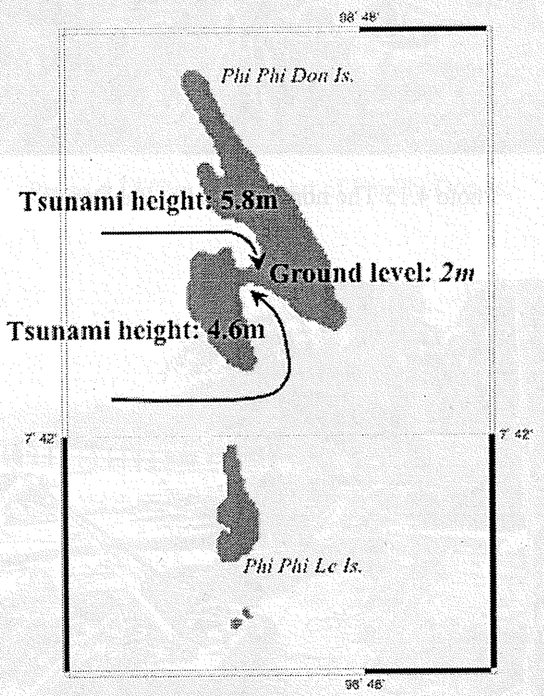


Fig. 4.13 Measured tsunami heights and ground level in Phi Phi Is.

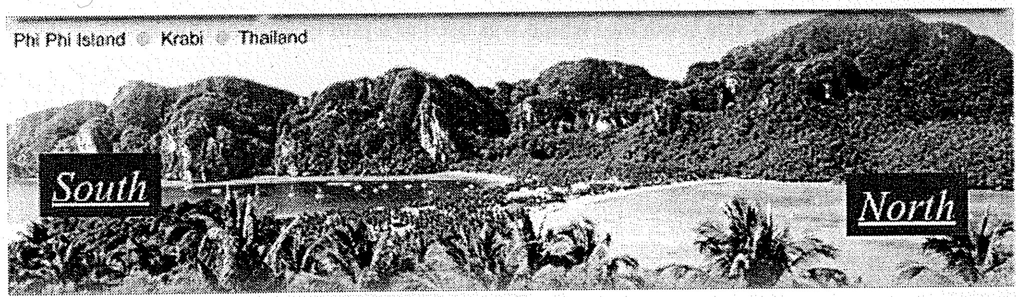


Photo 4.14 The north and the south bays of Phi Phi Don Is.

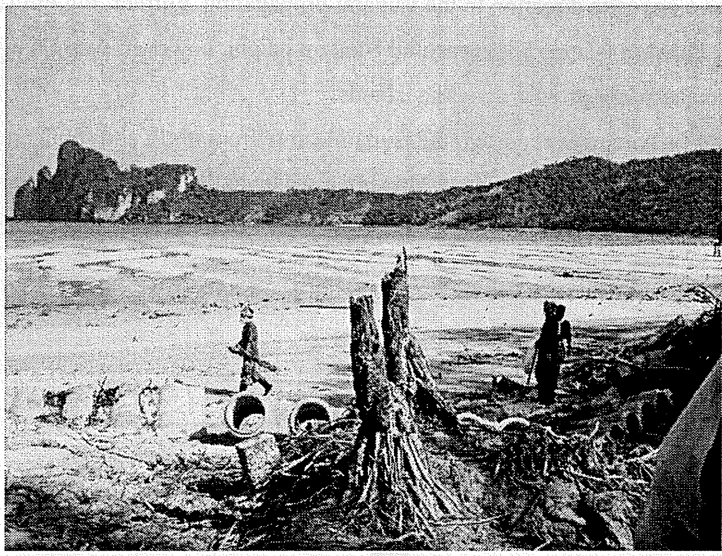


Photo 4.15 The north bay in Phi Phi Don Is.

Photo 4.16 The south bay which was used as a port in Phi Phi Don Is.

Photo 4.17 The central part of Phi Phi Don Is.

4.3 Numerical Simulation

4.3.1 Governing equations and numerical scheme

The numerical code is based on the linear wave theory in the polar coordinate system and no bottom friction is included. The linear wave theory is based on the depth-averaged equations of mass and momentum conservation. The conservation of mass can be written as

$$\frac{\partial \eta}{\partial t}+\frac{1}{R\cos\theta}\left[\frac{\partial M}{\partial \lambda}+\frac{\partial(N\cos\theta)}{\partial \theta}\right]=\frac{\partial \xi}{\partial t} \qquad (1)$$

where η is the water-surface elevation from its equilibrium state, λ and θ are longitude and latitude, the M and N are the depth-averaged volumetric flux in the (λ, θ) horizontal directions, respectively, ξ is sea bottom deformation by crustal movement, and t is the time. The conservation of linear momentum in the λ and θ directions are, respectively,

$$\frac{\partial M}{\partial t}+\frac{gh}{R\cos\theta}\frac{\partial \eta}{\partial \lambda}=fN \qquad (2)$$

$$\frac{\partial N}{\partial t}+\frac{gh}{R}\frac{\partial \eta}{\partial \theta}=-fM \qquad (3)$$

where R is the radius of earth, f is the Coriolis coefficient ($f=2\omega\sin\theta$, ω:angular velocity), g is gravitational acceleration. The above three equations are solved numerically for the unknowns M, N, and η, using the staggered-grid leap-frog numerical scheme (Goto and Ogawa, 1982). We used the 2 minutes digital bathymetry data published Smith and Sandwell (1997). We resample this data and produced fine grid bathymetry data for numerical simulation. Range of computation area is in the region of 70E-105E and 5S-23N, which is shown Fig. 4.14. The grid size consists of 3 x 3 minutes grids (area a) in the whole, and 1 x 1 minute (area b, c), and 20 x 20 seconds (area d, e, f) in Table 4.4.

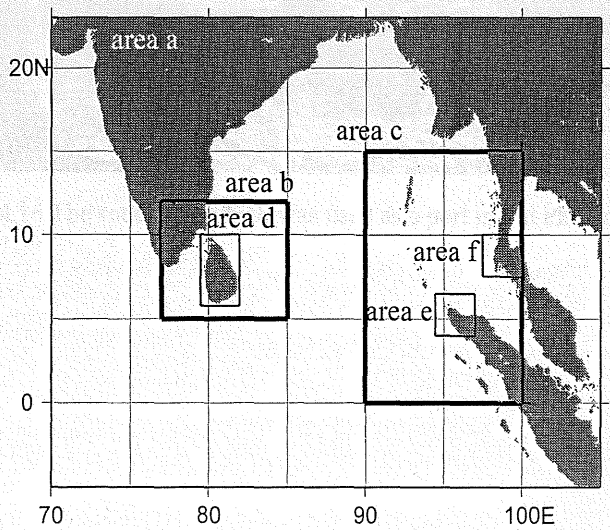


Fig. 4.14 Computation area and nesting system

Table 4.4 Parameters of computation area and nesting system

area	Grid size	Longitude		latitude	
a	3 min	70E	105E	5S	23N
b	1 min	77E	85E	5N	12N
c	1 min	90E	100E	0	15
d	20 sec	79.5E	82E	5.75N	10N
e	20 sec	94.5E	97E	4N	6.5N
f	20 sec	97.5E	100E	7.5N	10N

4.3.2 Tsunami Source Model

For the present numerical simulations, the initial fault displacement was inferred from one of the two Harvard CMT solutions (Table 4.5). Two fault models assumed to cover distribution of aftershocks, and these sizes are similar, 500km x 200km. The resulting sea floor deformation was computed by the theoretical method (Mansinha and Smylie, 1971) (Fig. 4.15). Then crustal rigidity is 4×10^{-11} dyne/cm^2. In numerical computation, dynamic fault parameters are considered. That is, sea bottom deformation starts at the point of main shock, and radiates at rates of rapture velocity 2.5km/s. Rise time at the each point is 0.1 second. Time for crustal deformation is about 400 seconds, because length of whole faults area is larger than 1000km.

Table 4.5 Fault parameters

	south	north
L(km)	500	500
W(km)	200	200
depth(km)	28.6	28.6
Strike	329	360
Dip	8	8
Slip	110	110
Dislocation(m)	5.0	5.0
Mo(dyne cm)	4.0×10^{29}	

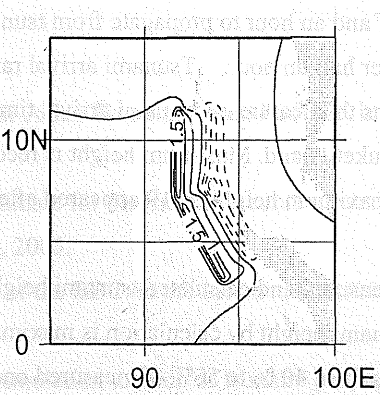
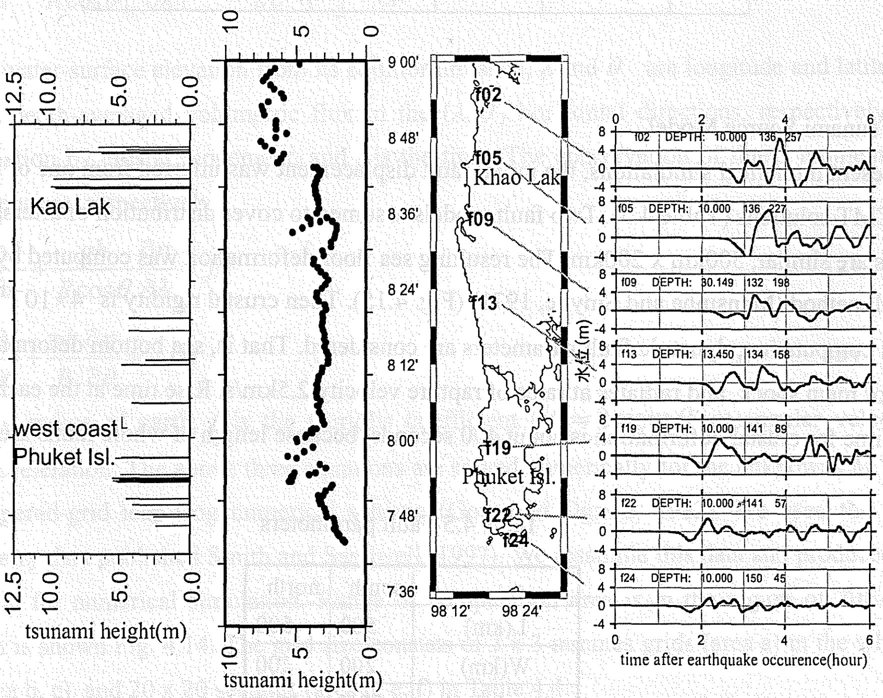


Fig. 4.15 Sea bottom deformation, gap among contour lines is 0.5m.

4.3.3 Results of numerical simulation

Fig. 4.16 shows distributions of measured and calculated tsunami heights along coast of Thailand. Maximum calculated height in Phuket Island is about 6m and similar to measured one. At Khao Lak, maximum calculated height is about 8m, and measured one is larger a little, which ranges from 9 to 10m. However calculated result describes difference between heights in Phuket and at Khao Lak as shown in measured distribution. Therefore both results are harmonious, and this indicates total energy of two fault models is acceptable for tsunami heights in Thailand.



(a)measured result (b)calculated result (c)time series output

Fig. 4.16 Comparison between calculated and measured tsunami heights distributions in Thailand, and time series output by calculation along shore

Fig. 4.16 also shows time series output along the coast of Thailand. Tsunami arrived at the southern part of Phuket Island at first. It took a half and an hour to propagate from tsunami source. Water surface descended firstly and ascended after half an hour. Tsunami arrival ran to the north direction along the coast of Thailand. Witness confirms this feature on tsunami arrival time. Tsunami arrival time at Khao Lak is an hour later than one in Phuket Island. Maximum height is recorded by the second or later ascent wave at four points. Especially maximum height at f19 appeared after a half and four hours of earthquake occurrence.

Fig. 4.17 shows distributions of measured and calculated tsunami heights in Sumatra Island. Along the northern coast of Banda Ache, tsunami height by calculation is maximum 4m and decreases with moving to the west. Calculated heights ranges from 40 % to 50% of measured ones. Along the western coast of northern Sumatra, tsunami height is maximum 10m, and about 5m at the same coast region of measurement. Measured heights are much larger than calculated ones. The reason for the difference between calculated and measured results is uniformity of two assumed fault models. That is, real fault movement has plural asperities, and it caused giant tsunami, which attacked to the west coast of northern Sumatra Island.

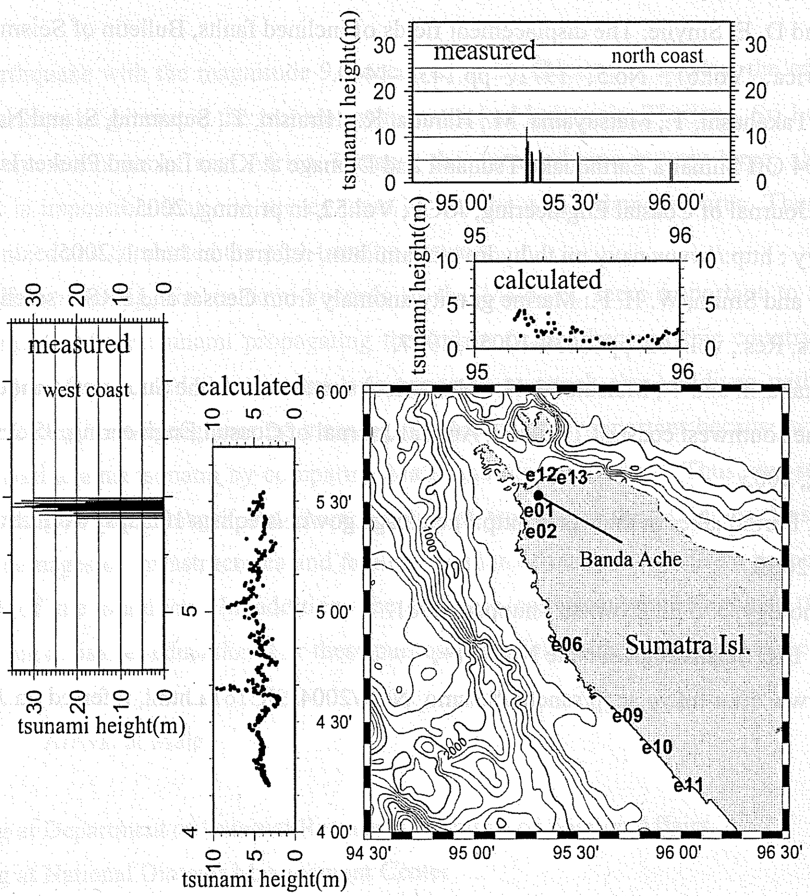


Fig. 4.17 Comparison between calculated and measured tsunami heights distributions in northern Sumatra.

These results of tsunami heights in Thailand and northern Sumatra Island indicates as follows:

1) There are plural asperities on the fault planes.
2) Uniformity in tsunami source made giant tsunami at the northern Sumatra.
3) However it has no effect to the coast at the distance of more than 500km.

References

Asian Tsunami Video.com : Amateur Asian Tsunami Video Footage, http://www.asiantsunamivideos.com/, referred on June 1, 2005

Abe, K. : Revised Mt and run-up estimate for the Indian Ocean Tsunami, e-mail to ITIC Tsunami Bulletin Board posted on January 26, 2005.

BBC : bbc.co.uk homepage - Home of the BBC on the Internet, http://news.bbc.co.uk/, referred on February 28, 2005.

Goto, T and Y. Ogawa: Numerical simulation method of tsunami propagation with the staggered leap-frog scheme, document of Tohoku Univ., 52p, 1982 (in Japanese).

Imamura, F., T. Nagai, H. Takenaka, and N. Shuto: Computer graphics for the study of transoceanic propagation of tsunamis, proceedings of the 4th Pacific Congress of Marine Science and Technology 90, pp118-123, 1990.

Mansinha, L. and D. E. Smylie: The displacement fields of inclined faults, Bulletin of Seismological Society of America、Vol.61、No.5、1971、pp.1433–1440.

Matsutomi, H., Takahashi, T., Matsuyama, M., Harada, K., Hiraishi, T., Suparatid, S. and Nakusakui, S. : The 2004 Off Sumatra Earthquake Tsunami and Damage at Khao Lak and Phuket Island in Thailand, Annual Journal of Coastal Engineering, JSCE, Vol.52, in printing, 2005.

Royal Thai Navy : http://www.navy.mi.th/hydro/tsunami.htm, referred on June 1, 2005.

Sandwell, D. T. and Smith, W. H. F.: Marine gravity anomaly from Geosat and ERS-1 satellite altimetry. J. Geophys, Res., vol.102, pp10039-10050, 1997.

Suzuka, A., Takahashi and T., Matsutomi, H. : Numerical simulation on the Sumatra earthquake tsunami along the southwest coast of Thailand, Annual Journal of Coastal Engineering, JSCE, Vol.52, in printing, 2005.

USGS : Largest Earthquakes in the world, http://neic.usgs.gov/neis/eqlists/10maps_world.html, referred on June 1, 2005.

Utsu, T. : Seismology, 376 p., Kyoritsu Shuppan, 2001.

Yamanaka, Y. : EIC Seismological Note No. 161+, http://www.eri.u-tokyo.ac.jp/sanchu/Seismo_Note/2004/EIC161a.html, referred on June 1, 2005.

Chapter 5 Survey of the tsunami damage in the Maldives

5.1 Outline of the Survey

The huge earthquake with the magnitude 9.0 occurred in 26, December, 2004 at the offshore of north Sumatra. This earthquake generated the tsunami, which attacked Indonesia, Thailand, Sri Lanka, India, the Maldives, and some countries of east Africa. Because the damaged area is very large, almost the entire Indian Ocean, it is impossible that one survey team covers the whole damaged area. Thus, many survey teams were organized and conducted the post-tsunami surveys.

In the scientific meaning, the tsunami records in the Maldives seem important to understand the comprehensive image of the tsunami propagating the Indian Ocean, because this country locates in the center of the Indian Ocean, and the tsunami was expected to attack the Maldives without significant transform of waveform. In the engineering meaning, the Maldives is important because we can estimates the effect of seawall against tsunami by comparing Male' and the other island. Thus, our survey team was organized to investigate the damages and characteristics of tsunami in the Maldives. Based on the field examination on damages of infrastructures and facilities, a plan of restoration will be proposed to improve the safety level of the Maldives. In addition, the effective countermeasures against tsunami will be proposed, including a disaster education. For these purposes, the following examinations were conducted.

31 January: Arrival at Male'

1 February:

(1) Meeting at Department of External Resources, Ministry of Foreign Affairs

(2) Meeting at National Disaster Management Center

(3) Meeting at Ministry of Transport and Civil Action

(4) Meeting at Ministry of Environment and Construction

(5) Site Survey in Male' to evaluate the inundation area

2 February:

Group A:

(1) Meeting at the Maldives Airport Company Limited

(2) Site Survey in Hulhule (Male' International Airport) and Hulhumale'

Group B:

(1) Site Survey in Keyodhoo, in Felidhe (Vaavu) atoll

(2) Site Suevey in Muli, in Mulaku (Meemu) atoll

(3) Site Survey in Ribudhoo, in South Nilandhe (Dhaalu) atoll

(4) Site Survey in Gemendhoo, in South Nilandhe (Dhaalu) atoll

3 February:

Group A: Site Survey in Hittadhoo-Maradhoo-Feydhoo-Gan, in Addu (Seenu) atoll

Group B: Site Survey in Kaddhoo-Fonadhoo-Manndhoo-Gan, in Hadhdhunmathee (Laamu) atoll

Group C: Hanimaadhoo and Kulhudhuffushi, in South Thiladhunmadulu (Haa Dhaalu) atoll

4 February

(1) GroupA: Site Survey in Laguna Beach Resort, Vadoo Island Resort and Embudu Village, in South Male atoll

Group B: Site survey in Male'

(2) Final meeting at National Disaster Management Center

(3) Departure from Male'

5.2 Male'

Male' Island is protected by the solid seawalls because Male' city is the capital of the Maldives and the reef had been reclaimed completely. The Indian Ocean tsunami exceeded the seawall and inundated Male'; however, the island was not sunk below the water surface by the tsunami. This tsunami caused some damages in Male'; (1) several ships were carried and remained on the quay, (2) a part of sheet-pile quaywall in the north wharf was jutted out over the port. However, those damages were not so severe and recovered quickly. The proper measures were enforced by the Maldives' government after the disaster, although those were enabled by the fact that Male' kept in the normal situation. If Male' island became inhabitable or the port facilities were destroyed severely, the influences on the Maldives' society were immeasurable both economically and mentally. In this sense, the tsunami event occurred in Male' should be investigated carefully.

Fig. 5.1 shows the tide record at Male', where the sea surface elevation from the mean sea level (M.S.L.) is drawn in centimeter. This figure suggests that the sea level at the tsunami arrival was almost the same as the M.S.L., -5~6cm, and the maximum tsunami height was approximately 1.45m. Note that the tide gage is installed in the atoll side, thus this tsunami height is that in the north side of Male'.

The representative of the crown height of seawall is 1.96m in the west coast, 1.36m in the north coast, 2.16m in the east coast, and 1.46 to 3.36m in the south coast from the M.S.L., although the crown height is partially higher. The representative crown height of quaywall is 1.16m in the north and south wharf. Thus, the tsunami might overflow the quaywall in the north and south wharf. It is possible that the tsunami height in the south and east coast is slightly different from the tide record, because the east and south coast of Male' faces the out of atoll. The atolls might be a kind of obstacle for the tsunami, so the tsunami flow probably concentrated in the channel between the atolls. Thus the tsunami height in the south coast was probably amplified slightly. The tsunami height in the east coast, also, may be amplified because the tsunami was dammed by Male' Island in the east coast.

Because Male' Island was not submerged below the tsunami as stated above, the trace height in Male' does not agree with the tsunami height. Thus, the inundation height in Male' has no importance in the scientific meaning. However, the inundation area of Male' is important in the engineering meaning, thus that was examined in our survey.

The boundary of inundation and non-inundation area was determined at every street by the eyewitness evidences of the residents. Fig. 5.2 shows the measured result of the inundation area in Male' Island. The inside of the blue line in the figure was not inundated, and the inundation area is approximately 60% of the island. The ground elevation of the boundary of inundation is approximately 1.1m almost over the island. This fact may indicate that the total volume of the overflowed seawater reached the 1.1m-line when the seawater was stored in the seawalls like a reservoir. On the other hand, the ground elevation of inundation-boundary in a part of north coast and a part of east coast is higher than 1.1m. In this region, the overflowed water might have some inertia force, and reached the high ground temporally.

Because the tsunami height was higher than the crown height of quaywall, it is thought that the inundated seawater mainly entered over the quaywall in the north and south wharf. However, Fig. 5.2 shows that the overtopping over the seawall at the east coast was not negligible. The tsunami height, perhaps, was amplified in the east coast because the tsunami was dammed by the island there; and it made the overtopping of the swell and wind wave over the seawall easy.

Fig. 5.3 shows the comparison of the inundation area and the reclamation area in Male' Island. The blue line denotes the inundation boundary, and the black line the shape of the original Male' Island. This figure indicates that the reclamation land was fully inundated by the tsunami, and the inundation area was very similar to the reclamation area. Note that the reclamation land is relatively danger in comparison to the original land if the protection level (e.g. crown height of seawall) is the same.

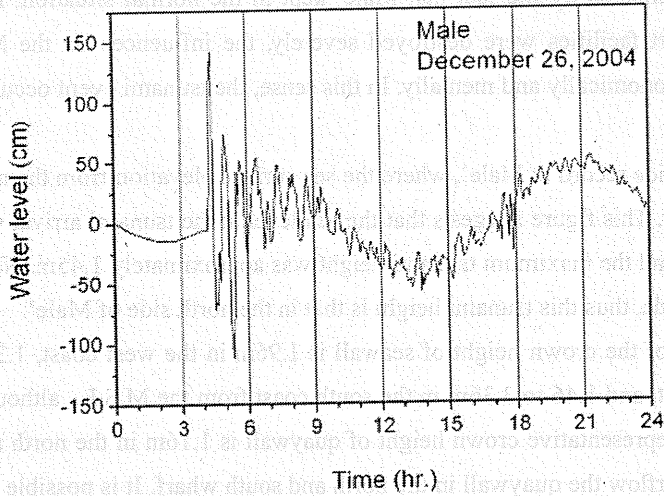


Fig. 5.1 Tide record at Male' (time in UTC, tide level in centimeter from M.S.L., measured and provided by Sea Level Center, University of Hawaii)

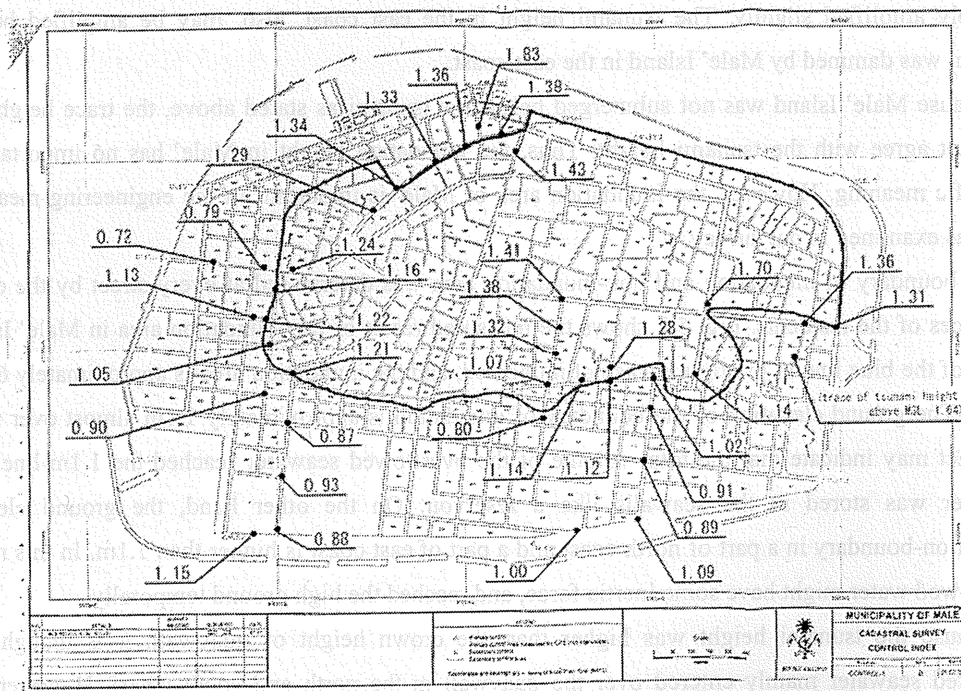
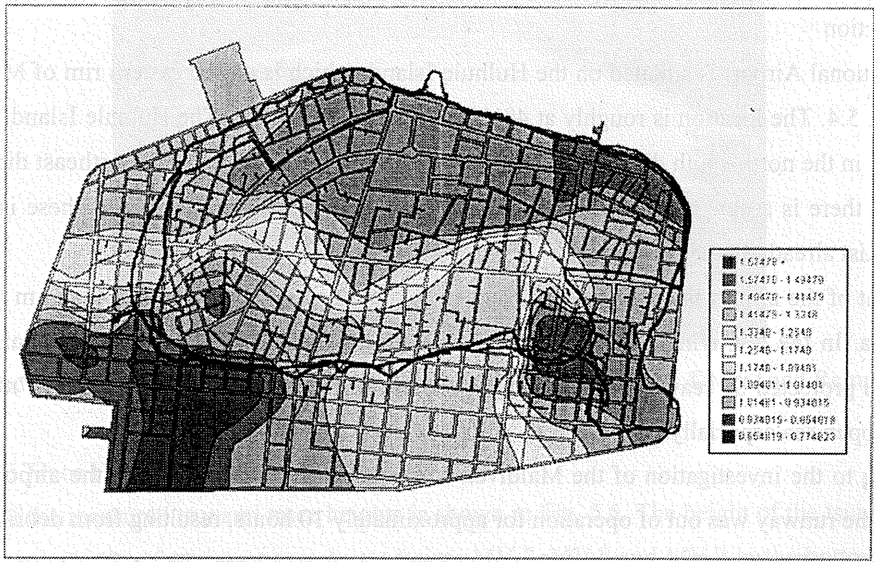


Fig. 5.2 Inundation area in Male' and the ground elevation near the boundary of inundation



Elevation contour map and street map of Male' overlaid (elevations are given in Metres). (Male' height points acquired from DGPS and interpolated using MapInfo software)

Fig. 5.3 Comparison of the inundation area (blue line) and the shape of the original island (black line)

5.3 Male' International Airport (Hulhule) and Hulhumale'

5.3.1 Introduction

Male' International Airport is situated on the Hulhule Island, which is on the eastern rim of Male' Atoll, as shown in Fig. 5.4. The location is roughly at 4°11´29"N and 73°31´45"E. The Hulhule Island is a long and narrow island in the north-south direction. The tsunami came from the east. In the northeast direction of the airport island there is a new reclaimed island, Hulhumale', and a causeway connects these islands. Many apartments exist already in the Hulhumale'.

The height of the airport island is about 1.7m above the mean sea level and less than 1m locally in the west side area. In the low-lying area, high waves overtopped sometimes before the tsunami. The airport facilities were protected by seawalls whose heights varied from M.S.L.+2.0m to M.S.L.+2.7m in the areas facing to the open sea especially.

According to the investigation of the Maldives Airports Co. Ltd., two-thirds of the airport island was flooded, and the runway was out of operation for approximately 10 hours, resulting from debris and detritus due to the tsunami flooding. The runway lights were repaired after 18 hours. Photo 5.1 shows the inundated airport by the tsunami. The runway was flooded and coral sand flowed out of the island.

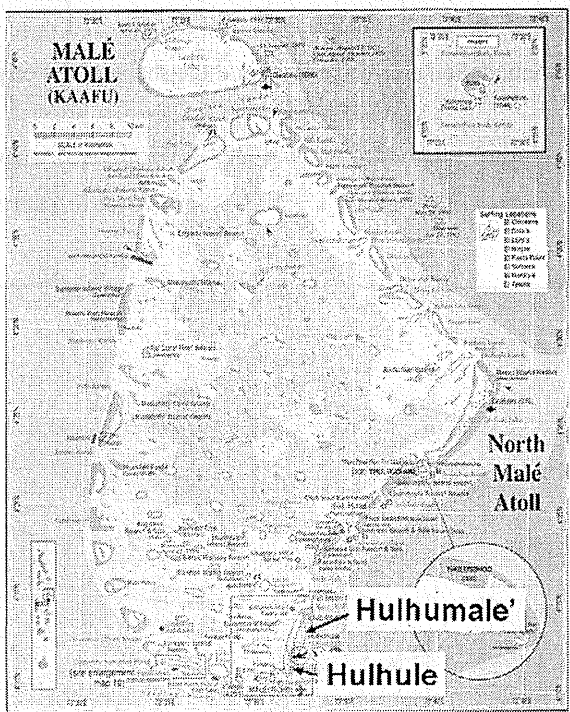


Fig. 5.4 Male' Atoll and Hulhule Island (The based map is from Atlas of the Maldives, 2004, ©Atoll Editions.)

Photo 5.1 Male' International Airport inundated by the tsunami. ©Mr. Todd Rempel

5.3.2 Tsunami Trace Height

A summary of the measured tsunami trace heights is shown in Fig. 5.5. The height of the tsunami attacking the airport was more than 2m approximately. At Points MV-7, MV-8 and MV-9 in the bottom of the inner sea area between the causeway and the airport, there were high records. According to tsunami observers at Points MV-8 and MV-9, three tsunamis attacked and the first tsunami came from the east direction around 9:20 in local time. The second tsunami came a few minutes later after the first tsunami came and it was the biggest among all of the tsunami waves. Since the high tsunami trace heights were found around the bottom of the inner sea area, it seems that the second tsunami came through the inner sea from the north direction and it lost the places to go there. However, if the second tsunami passed in the north of Hulhumale' and changed the propagation direction into the inner sea area by the west reef edge, the time interval between the first tsunami and second tsunami is about 12 minutes, in which the inner sea area is assumed to be 5km long and 5m deep. If the second tsunami came from the west of the Airport Island, the propagation time is almost the same. These time intervals are different from the hearing results. Therefore, the tsunami in the bottom of the inner sea area was probably affected by local topography change and existence of structures. To clarify the characteristics of the high tsunami, we need a more detailed numerical simulation on the tsunami.

On the other hand, in Fig. 5.1 in the previous section, the tide record at the Male' tide station shows that the time interval between the first tsunami and second tsunami is about 40 minutes. The second tsunami in the tide record in the west of the airport island is different from the second tsunami in the inner sea. In the south of Sri Lanka, three tsunamis were observed, and the multiple tsunamis around Male' were the same as the tsunamis in Sri Lanka.

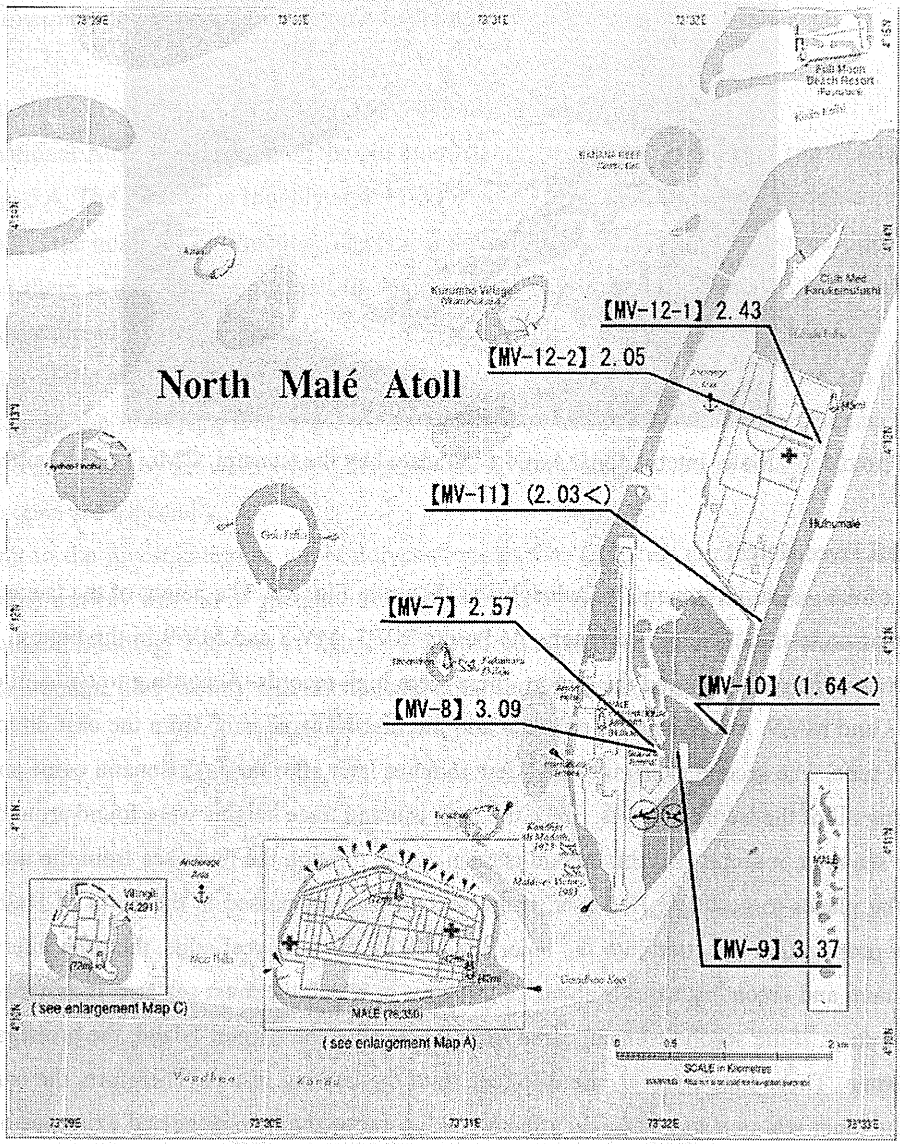


Fig. 5.5 Tsunami trace heights

5.3.3 Tsunami Damage on Structures

Fig. 5.6 shows some structural damages due to the tsunami. The most severe damages are along the inner sea between the causeway and airport.

In Huluhumale', the shore protection works which consisted of cement bags were partially damaged as shown in Photo 5.2. Although the tsunami flow washed some cement bags on the land about 15m apart from the coast, it seems that they were mainly destroyed by the backwash of the tsunami, judging from the feature of the scattered bags on the beach.

The east and west sides of the causeway were eroded by the tsunami action as shown in Photo 5.3. Tsunami pressure also broke an on-land wall even behind coastal houses as shown in Photo 5.4. Seawalls were damaged in some areas as shown in Photo 5.5, and especially in the east side of the airport along the inner sea area the seawall were collapsed as shown in Photo 5.6 by the high tsunami. The seawall which was made from coral stones covered by concrete suffered severe damage from the tsunami action. In the southwest side of the airport, parapets of the seawall were fallen down as shown in Photo 5.7. Since the south and southwest sides of the airport faces the open sea, high tsunami attacks there.

The tsunami forces acting on vertical walls can be evaluated the following empirical equation.

$$p = 2.2\rho g a_I$$

in which p : tsunami pressure (kN/m^2), ρ : water density (t/m^3), g : gravitational acceleration (m/s^2) and a_I : tsunami height (m). The tsunami height here is not the wave height of tsunami, and corresponds to the wave amplitude. For tsunami bores, it is the bore height. Using the equation, in the case of the tsunami of 2m high, the tsunami pressure is 44kN/m^2, or 4.5tf/m^2.

5.3.4 Another Tsunami Feature

There is an interesting comment from an observer of the tsunami. It is that the water surface bubbled in a waterway of the inner sea area and cream-colored water was extended around 8:45 before the first tsunami arrival. This may be caused by the tsunami pressure in the phase of the increasing water surface before the maximum water elevation of the first tsunami. The pressure was transmitted in the coral sea bottom in which there are some water paths, and it made coral sand spring from the sea bottom.

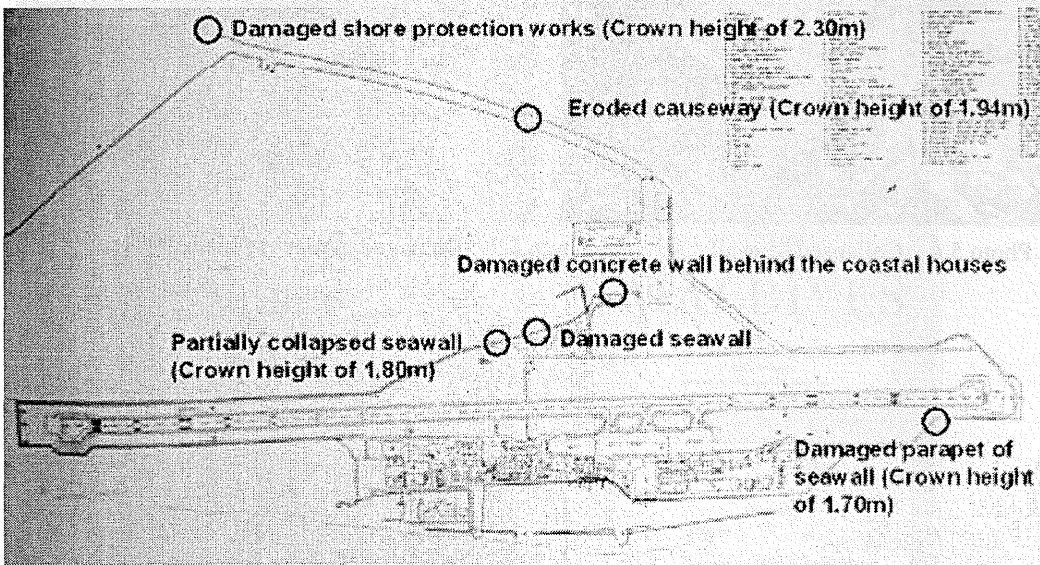


Fig. 5.6 Tsunami damages

Photo 5.2 Damaged shore protection works

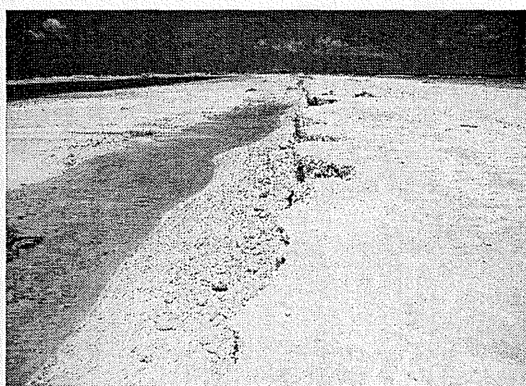


Photo 5.3 Eroded causeway

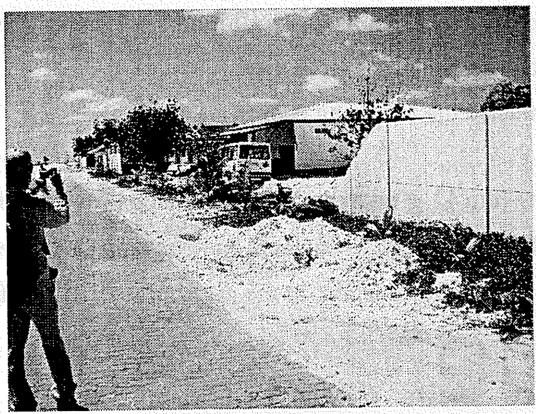


Photo 5.4 Damaged inland wall

Photo 5.5 Damaged seawall

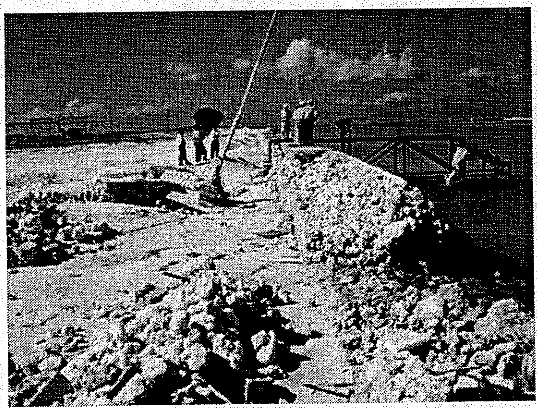


Photo 5.6 Collapsed seawall

Photo 5.7 Damaged parapet of seawall

5.4 Haa Dhaalu Atoll

In Is. Hanimaadhoo of Haa Dhaalu Atoll (see Fig. 5.7), height of the tsunami should have reached 1.7 m above the sea level, approximately. In this island, UHSLC has been collecting the data of sea level changes, and the record shows the abnormal fluctuations (Fig. 5.8).

We selected this island as one of our survey sites, because there is an airport and plays principal roles in the northern part of the Maldives. The survey started on February 3, 2005. In addition to Is. Hanimaadhoo, Is. Kulhudhuffushi (Photo 5.8, Fig. 5.9) is also surveyed. In this survey, we tried to determine the trace heights of tsunami by asking the residents, or by finding marks of tsunami on the walls and houses, and measured them.

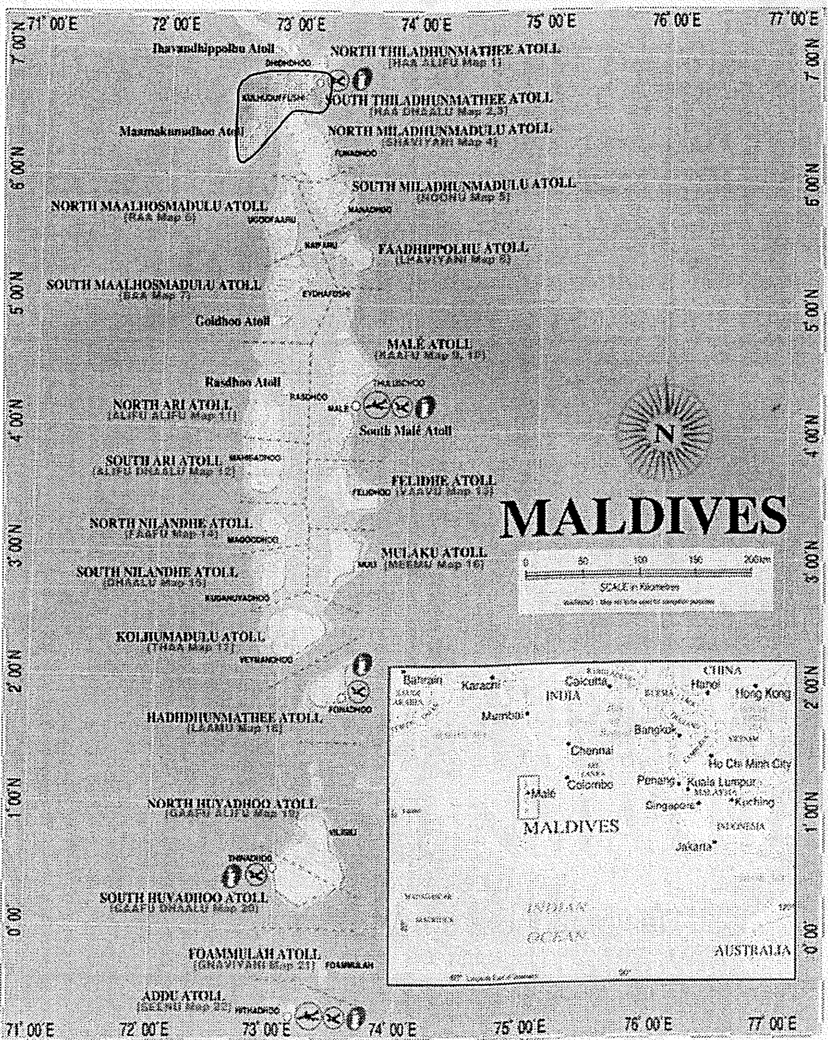
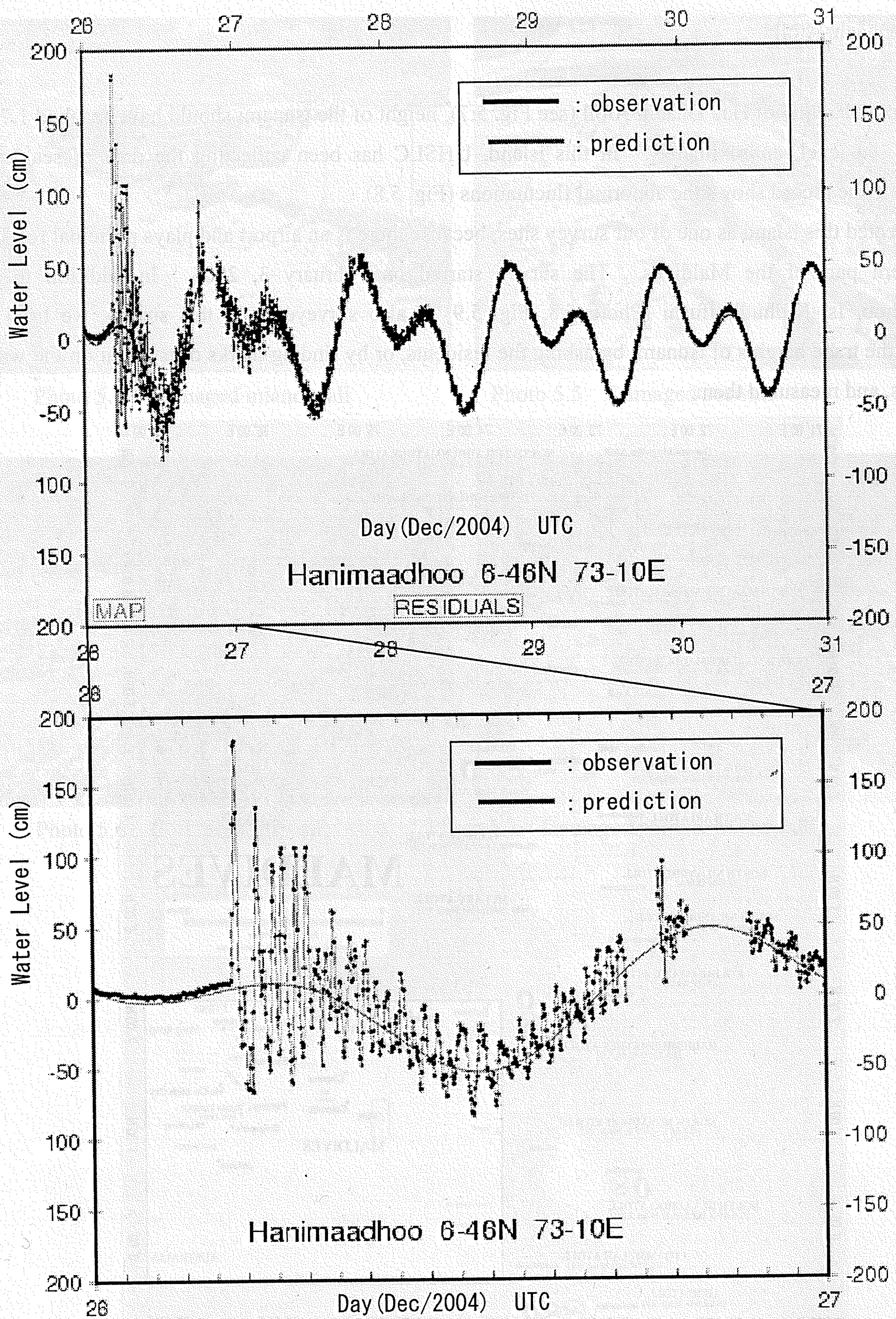


Fig. 5.7 Location Map of Haa Dhaalu Atoll (Based map is from Atlas of the Maldives, 2004, ©Atoll Editions.)



Reference : http://ilikai.soest.hawaii.edu/uhslc/iotd/ modified by H. FUJII

Fig. 5.8 Tide record at Hanimaadhoo(time in UTC, tide level in centimeter from M.S.L., measured and provided by Sea Level Center University of Hawaii)

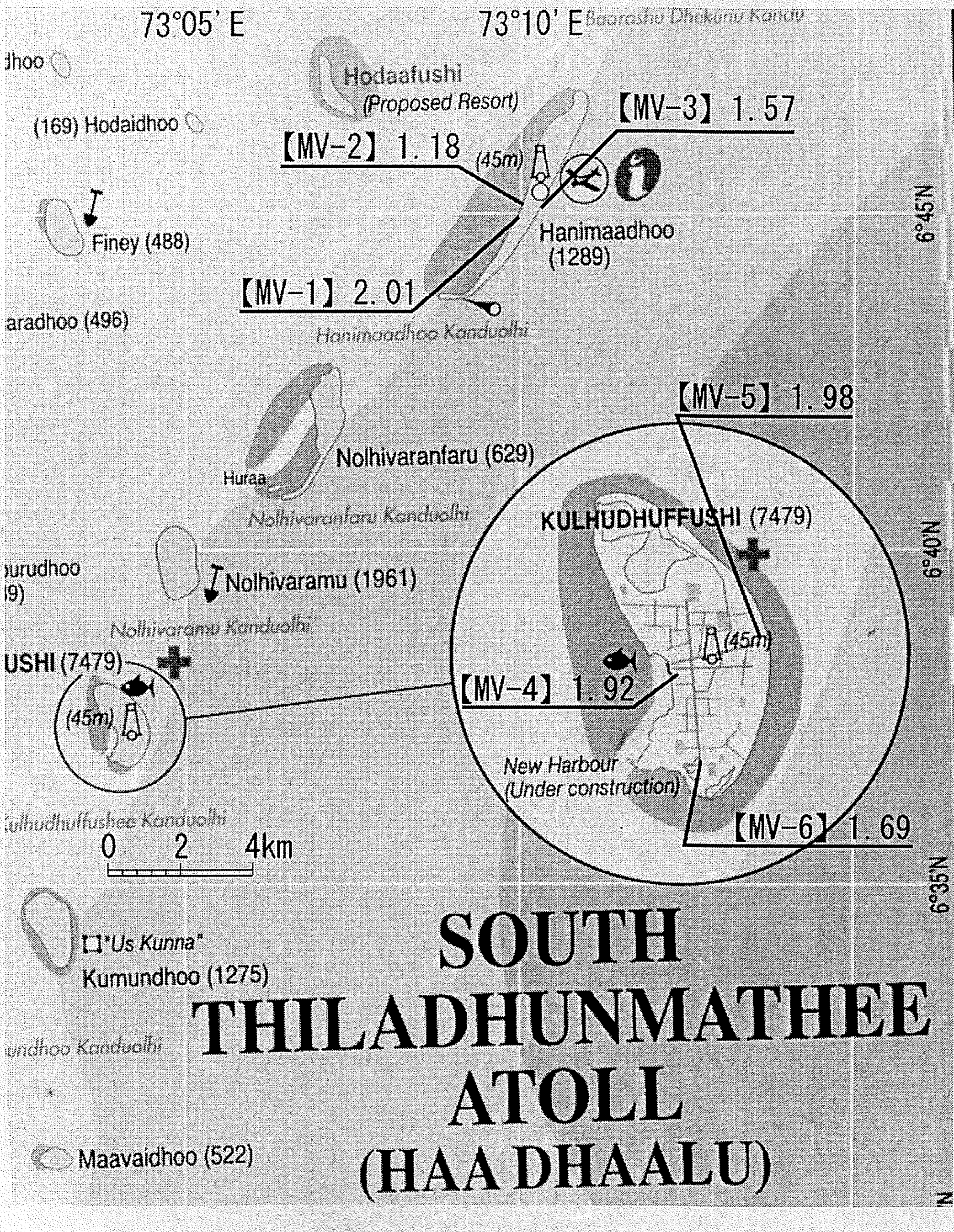


Fig. 5.9 Surveyed Sites and the Tsunami Trace Height in Is. Hanimaadhoo and Is. Kulhudhuffushi (unit: m; Based map is from Atlas of the Maldives, 2004, ©Atoll Editions.)

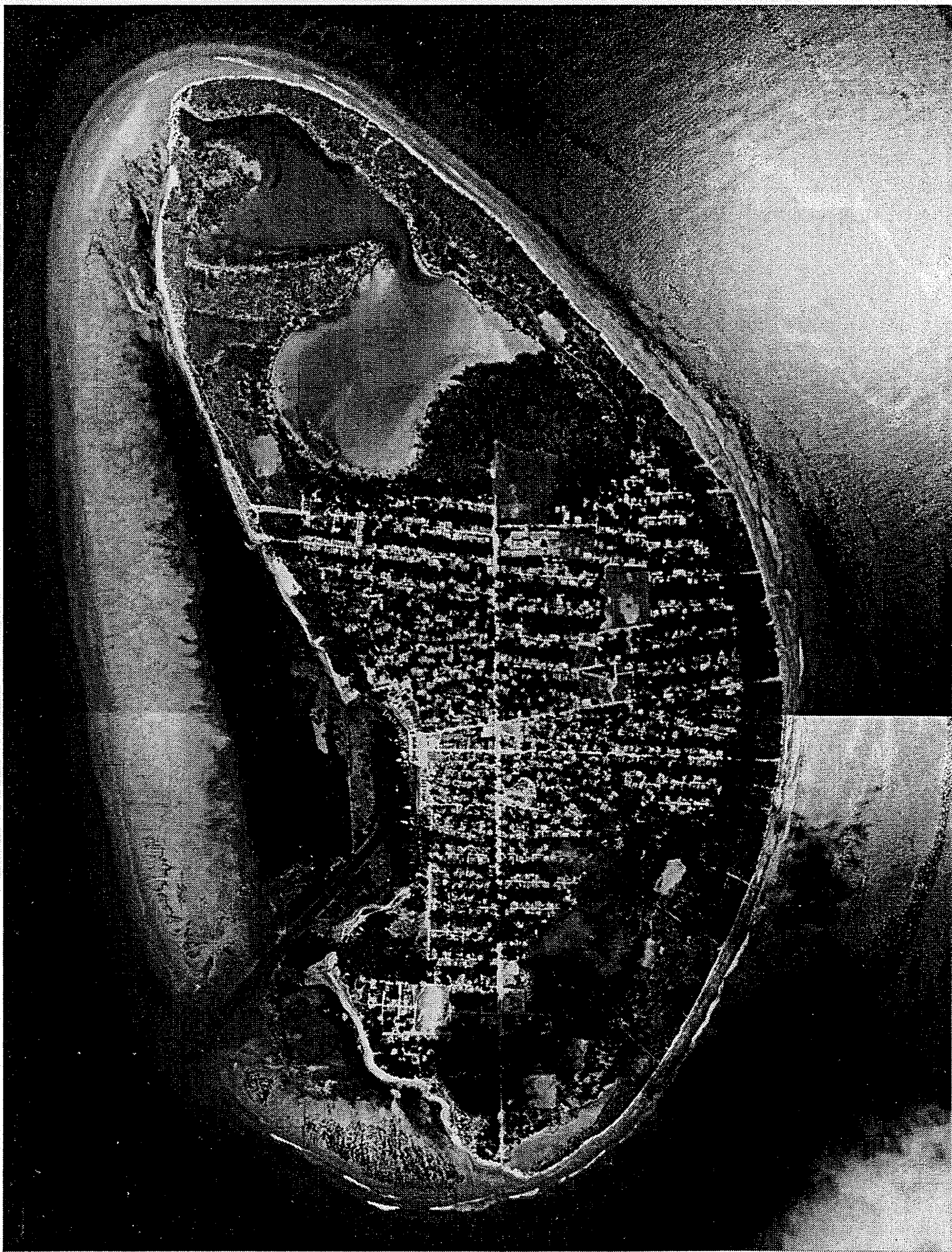


Photo 5.8 Is. Kulhudhuffushi

We tried to summarize the tsunami attacks on Haa Dhaalu Atoll by viewpoints from circumstances of inundation and tsunami trace height, as written below.

(1) Results of Survey on Is. Hanimaadhoo

According to the residents, the tsunami intruded the island both from east and west sides of the coast at the same time, like the water level rises gradually. The airport buildings, which locate west side of the runway, were inundated; however, the runway was not.

In the residential area at northern Is. Hanimaadhoo, there are no such incidents like collapses of neither houses nor walls. According to the residents, inundation occurred at beaches of east and west, residential area did not receive any intrusion of seawater.

Since no clear marks of tsunami were found, hearings were conducted on the residents, and the heights of tsunami trace were measured. Fig. 5.9 shows the location of measurement and the results. Photo 5.9 shows the sites.

(2) Results of Survey on Is. Kulhudhuffushi

According to hearings done on the residents of Is. Kulhudhuffushi, the tsunami came around both north and south of the island, and inundated the west area. It is found that the tsunami intruded the west coastal area from the north and the south.

The tsunami attacks on the Kulhudhuffushi could be summarized as below.

*West Coast

In the northern part of the west coast, collapsed houses and walls are observed (Photo 5.10). Several boats are thrown on the beach at the central part of the west coast.

*East Coast

Although Is. Kulhudhuffushis located the eastern end of the reef, the tsunami was blocked by berm, and little amount of tsunami body flew over it (Photo 5.11 site#【MV-5】); however, it reached a house at 116.5 m inland by flew down on gently sloped ground toward west. The depth was 6 cm deep at the house.

*North Coast

No marks were found at the north coast. The coast is consisted of hard coral and has steep slope. Numerous fragments of coral, which thought to be transported by the tsunami, were found in inland.

*South Coast

It was found that the wall of Ministry of Public Works was collapsed. There were the clear marks at the wall of the yard(Photo 5.11 site# 【MV-6】).

In Is. Kulhudhuffushi, three clear tsunami marks were found and the heights were measured. One site, which a residence's witnessed, was also measured. Fig. 5.9 shows points of measurement and tsunami trace height.   The measured sites were photographed as shown in Photo 5.11.

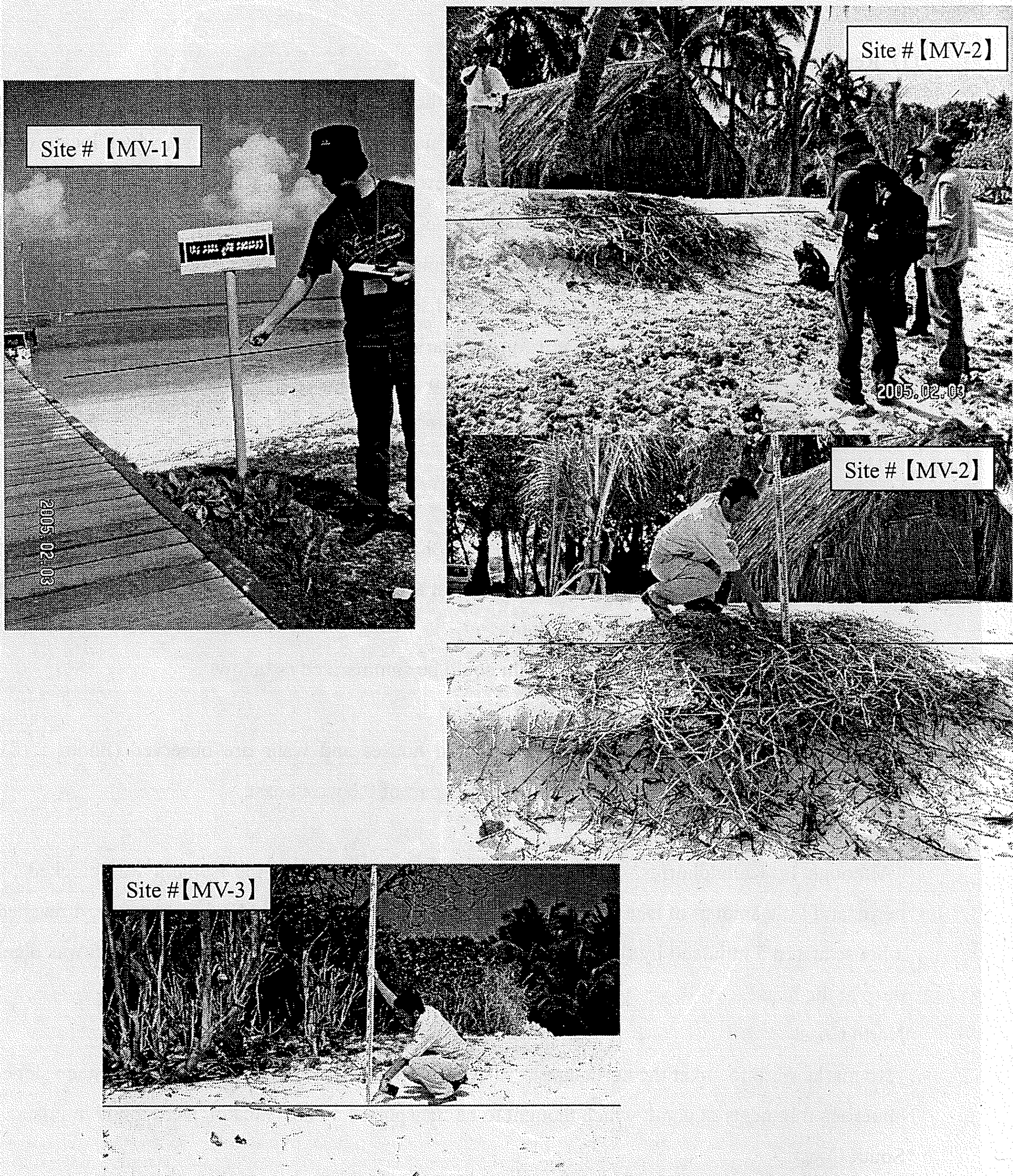


Photo 5.9   Site of Measurements in Is. Hanimaadhoo

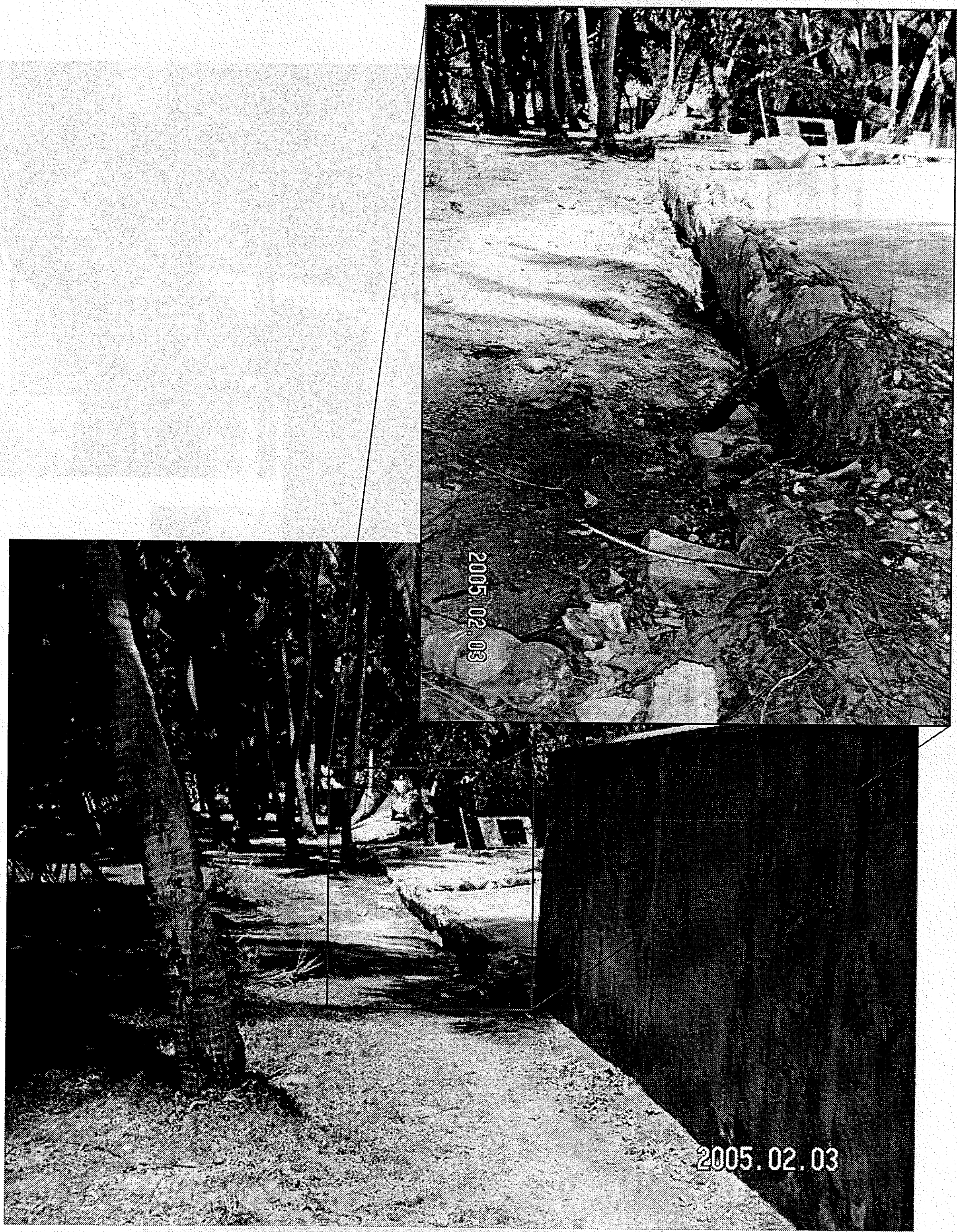
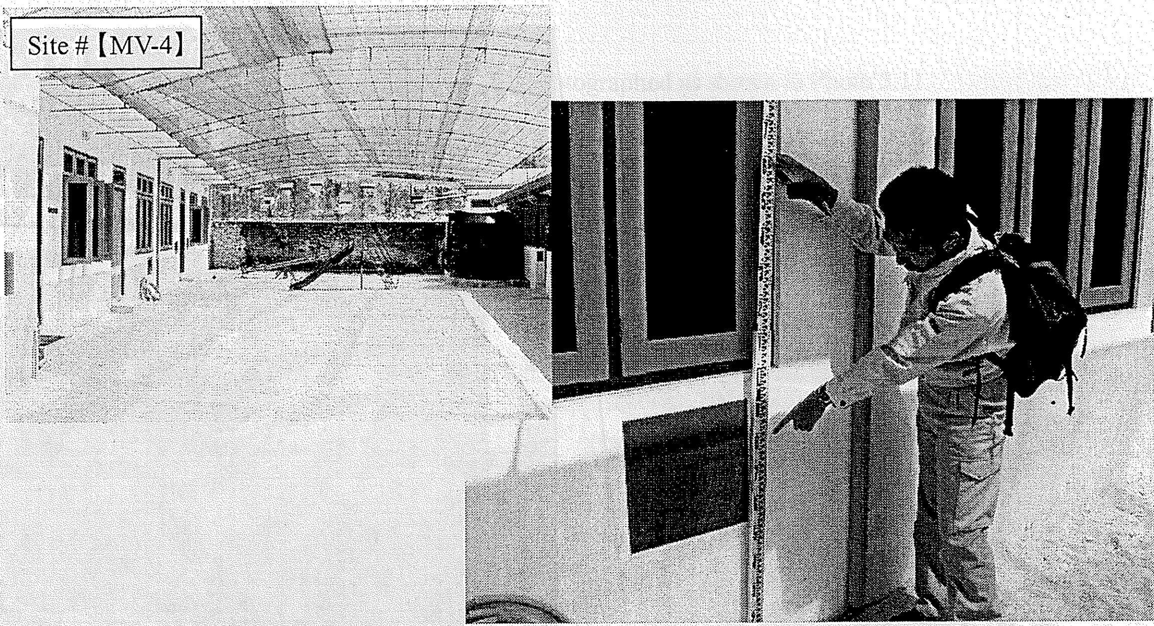


Photo 5.10 Collapsed Wall at North West Part of the Is. Kulhudhuffushi



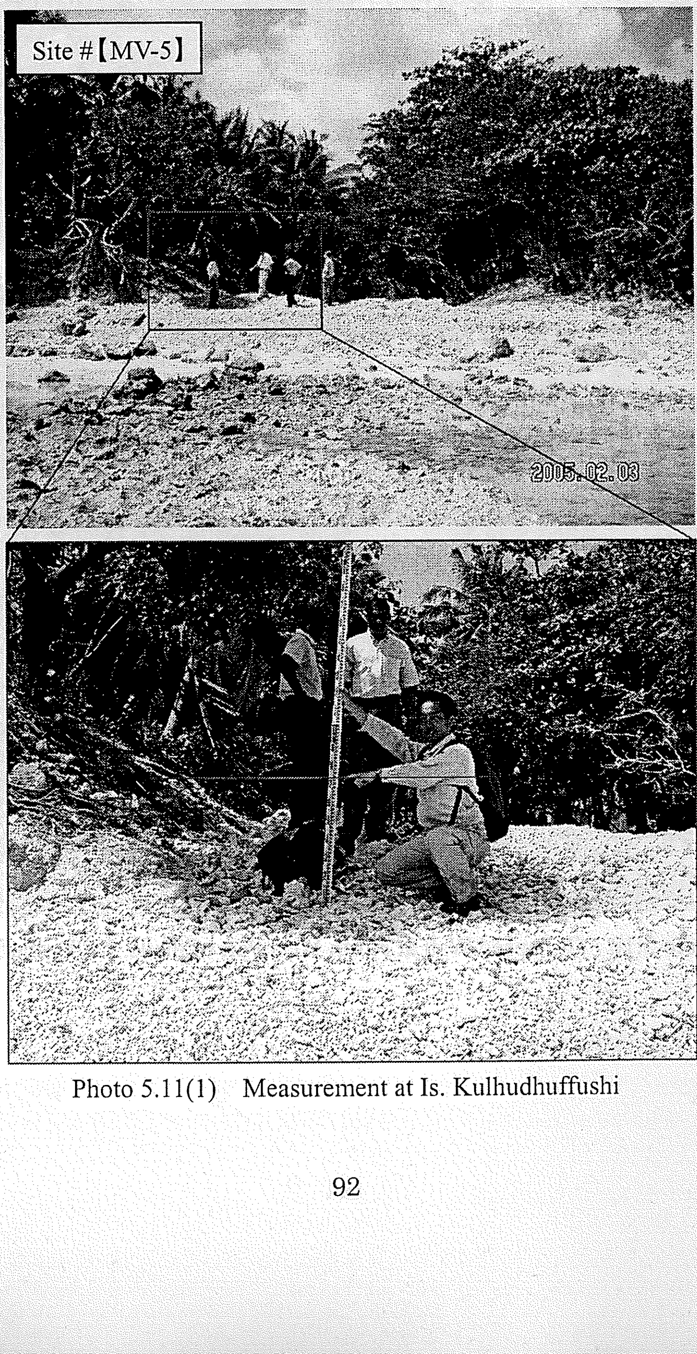


Photo 5.11(1)   Measurement at Is. Kulhudhuffushi

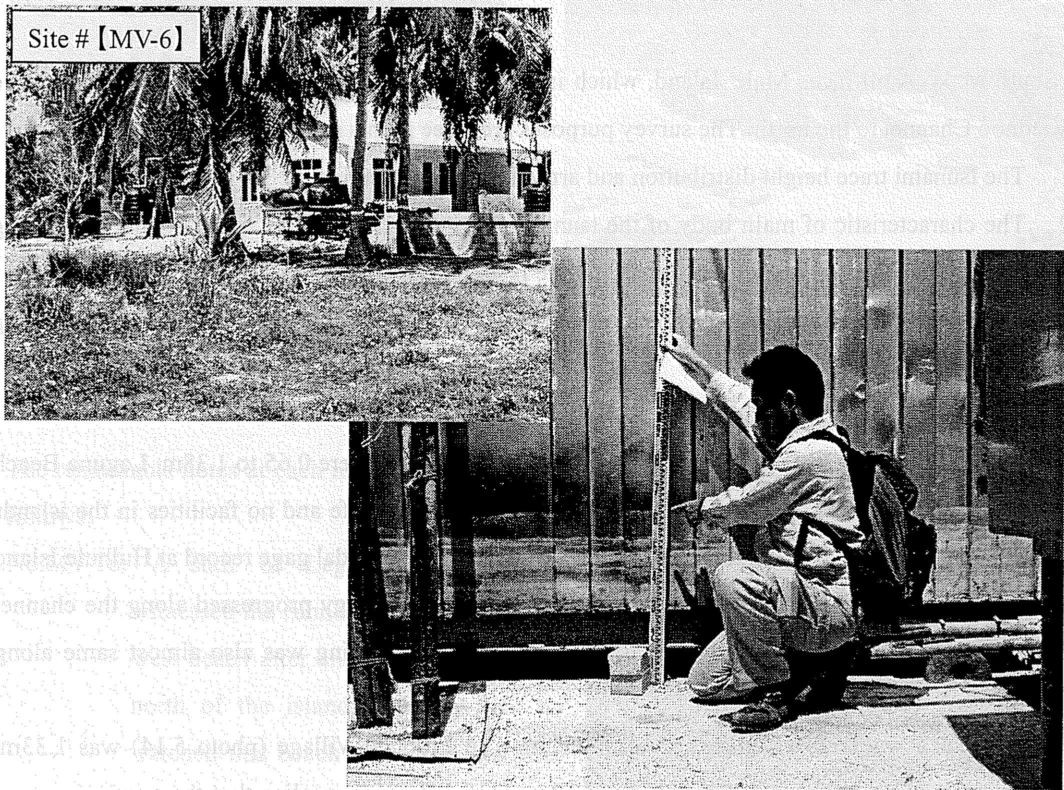


Photo 5.11(2) Measurement at Is. Kulhudhuffushi

5.5 South Male' Atoll

South Male' Atoll faces Male' Island, which is the capital of the Republic of Maldives, along the Vaadhoo Channel to the north. The survey purposes are three points as follows;

1. The tsunami trace height distribution and arrival time in the region are surveyed,
2. The characteristic of main body of the tsunami energy which attacked not only this atoll along the channel but also Male' Island and Hulhule Island is made clear,
3. Information of natural environment damage is collected by the interview to scuba diving instructors of resorts.

The tsunami trace heights along the channel shown in Fig. 5.10 were 0.65 to 1.38m. Laguna Beach Resort (photo 5.12) and Vadoo Island Resort (photo 5.13) were safe and no facilities in the islands were damaged. The maximum height 1.38m is almost same as the tidal gage record at Hulhule Island (International Airport). These results suggest that the tsunami energy progressed along the channel did not reduce well, and the right-angled energy against progressing was also almost same along there.

The height of water level at the inside of the atoll in Embudu Village (photo 5.14) was 1.33m, which was higher than that at the outside, 1.18m. This difference implies that the tsunami energy was held in the atoll. This island resort was also safe and was not damaged.

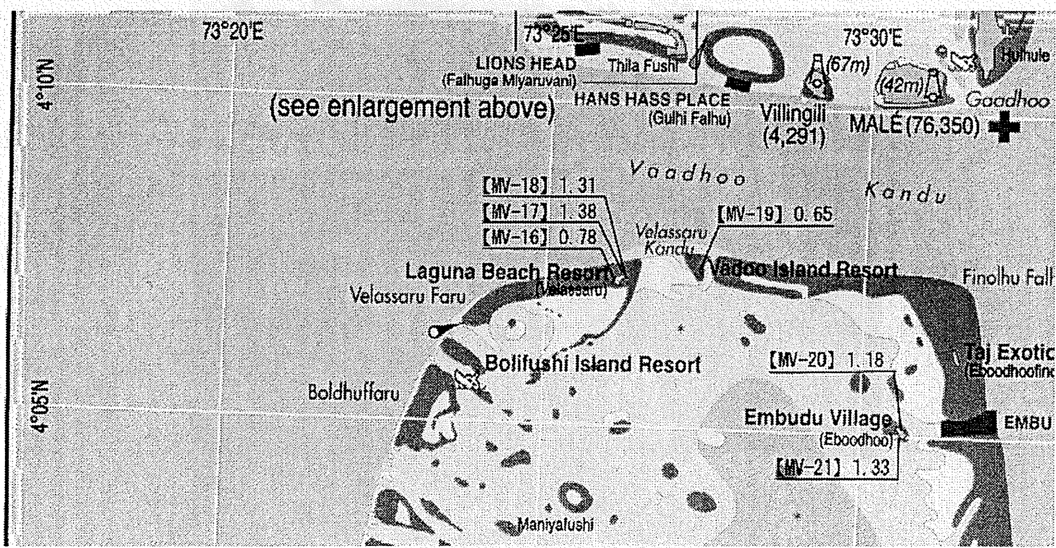


Fig. 5.10 Tsunami trace heights in South Male' Atoll

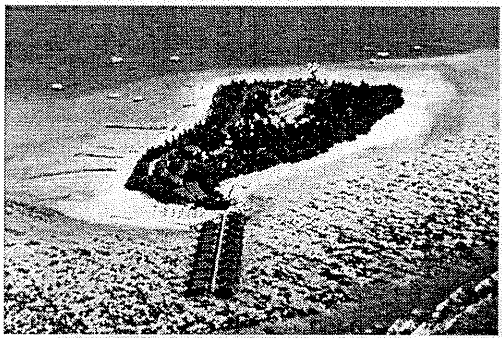


Photo 5.12　Laguna Beach Resort

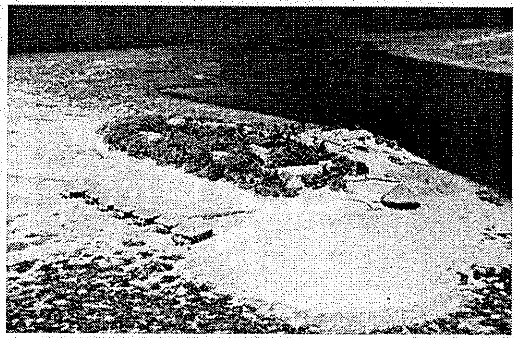


Photo 5.13　Vadoo Island Resort

The remarkable notes at each measured point are as follows;

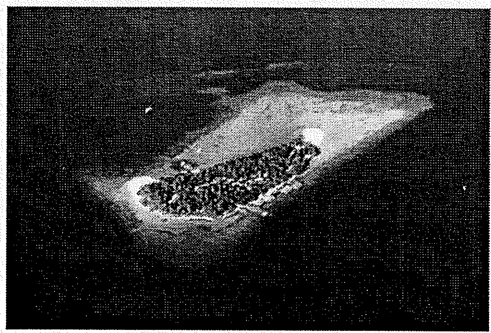


Photo 5.14　Embudu Village

No.MV-16: A staff of Laguna Beach Resort witnessed the running-up tsunami at this west beach after checking inundation at north of the island. It means that he watched this beach a few minutes after the tsunami main body came.

No.MV-17: White sandy trace had remained under a cottage terrace of which level was below the cottage floor.

No.MV-18: Same kind of white sandy trace had been on the side of flowerpot (photo 5.15). Wind waves on the tsunami from north overtopped sea walls.

No.MV-19: Scuba diving instructors had measured this height at a step of pier (photo 5.16). They recognized the tsunami already had come to the Maldives before the water level raised because they found quite fast currents had occurred in a channel between Vaadhoo Channel and inside of this atoll.

No.MV-20: One resort-beach staff in Embudu Village looked the tsunami and took the picture by his mobile phone near the pier which connects to cottages on the water (photo 5.17). The tsunami water level was a little lower than this island ground level. Some part of wind wave on the tsunami only ran and moistened the ground.

No.MV-21: The owner and staffs witnessed that the water came from the inside of the atoll to the level just below the restaurant's floor.

Photo 5.15

Trace at Laguna Beach Resort

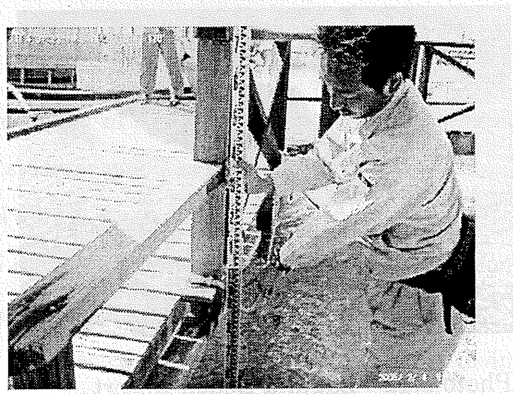


Photo 5.16

Trace at Vadoo Island Resort

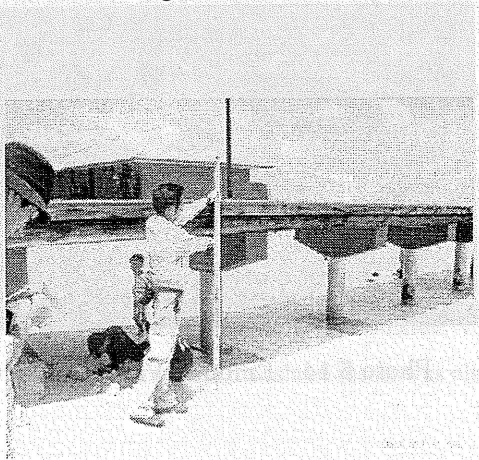


Photo 5.17

Trace at Embudu Village

At 9:11 AM on 26th December, Japanese scuba diving instructors of Vadoo Islands Resort received the initial impact of tsunami in a small channel along this island. They noted down the currents and water level fluctuation to a sheet, which is shown in Fig. 5.11 and Fig. 5.12.

The '9:11' is remarkable time because of the earliest record of the tsunami in the Maldives. In order to check the safety before visitors dive, one instructor was diving as routine work at the small channel along the island which connects from

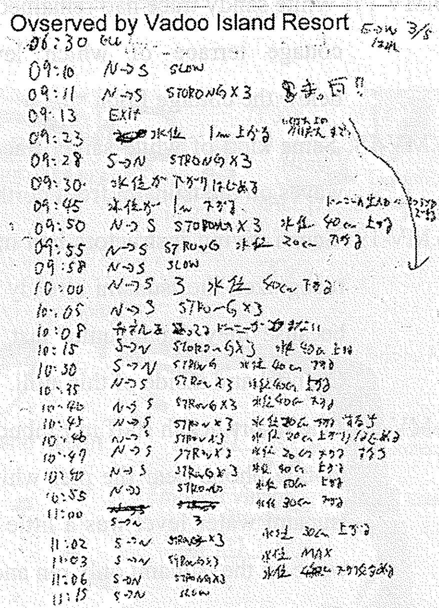


Figure 5.11 Tsunami Record provided by Vadoo Island Resort

Vaadhoo Channel to inside of the atoll. The current directed to inside of the atoll was too fast for the professional of diving, did not let him swim or stay by holding a rock either. He escaped to inside of the atoll because he knows that currents in the inside are slow as compared with those in the small channel.

As celerity of a tsunami is fast in the deep sea, the water level in Vaadhoo Channel rose earlier than the record of the tidal gage at Hulhule Airport. Since the energy concentrated to the progressing direction, the gradient of water level between the channel and the atoll became steep. This was the driving force of the initial fast current.

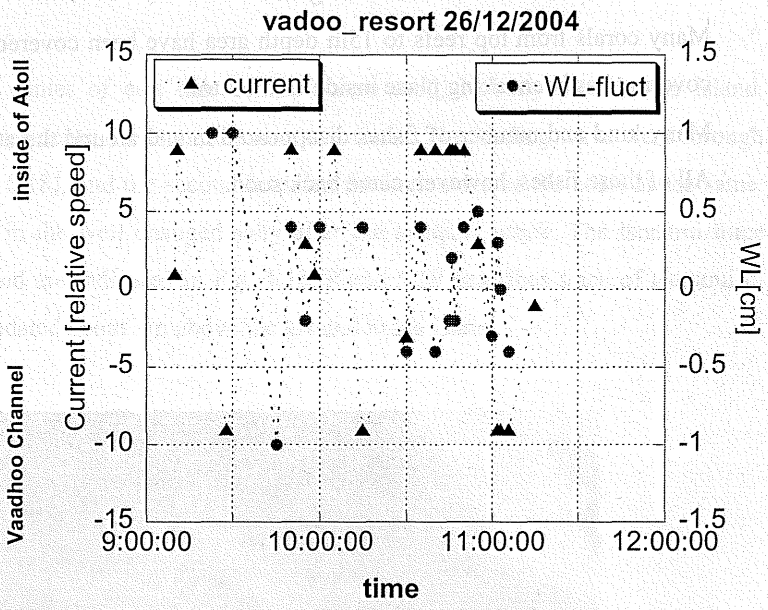


Figure 5.12 Tsunami records at Vadoo Islands Resort

In the inside of South Male's Atoll, the large strong circulation was witnessed during a few hours, of which direction changed many times clockwise and counter-clockwise. The phenomena also express a part of tsunami energy was held and fluctuated in the atoll. On the other hand, another scuba diving instructor did not feel tsunami or strong current at a northern area of Vaadhoo Channel.

The following natural environment damages were watched by the resort staffs and the scuba diving instructors.

- A heavy coral rock of which weight was about a few hundred kilograms moved.
- Much silt and sand moved to deep zone where water depth is 15m or more than.
- Turbidity in the channel and atoll rose by silt of corals during two weeks after the tsunami attacking. Many staffs of resorts described that sea water around islands became milk color.
- Small branching corals were damaged at some area along Vaadhoo Channel.
- Some branching and poritidae corals rolled off from shallow area to deep area.
- Some middle size of branching corals was also damaged. On the other hand, no large branching

coral over 1m in diameter was damaged.

- Many corals from top reefs to 15m depth area have been covered by the sand. Particularly the covering has been taking place inside of the Atoll.
- Many kind and number of fishes disappeared in and around the atoll at once just after tsunami. All of these fishes, however, came back soon.

5.6 Vaavu Atoll

Keyodhoo is located in the center of east side of the Vaavu atoll, Nobody died in the island. According to hearing on the residents, the tsunami came two times. The leading wave went through from east to west (see Photo 5.18), and the second intruded the both sides of the coast at the same. Moreover, the ground water in the well changed salty after the tsunami attack. The tsunami trace heights measured in this island are indicated in Fig. 5.13. Photo 5.19 describes trace of tsunami in house. Everywhere were inundated about 1m above the ground in the island.

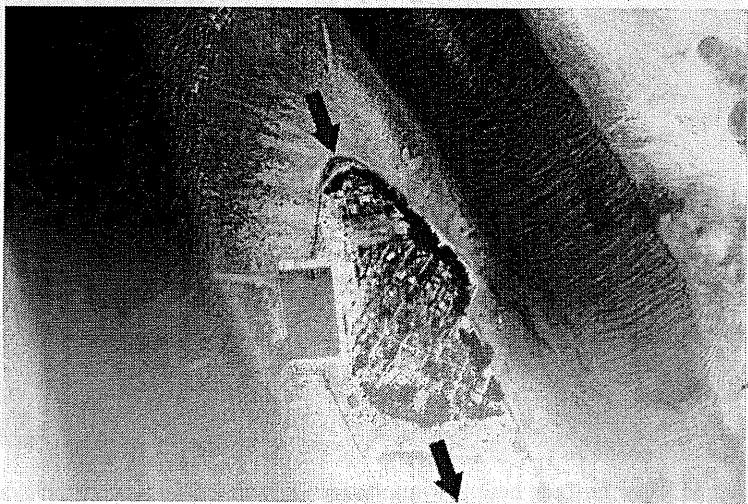


Photo 5.18 Direction of tsunami in Keyodhoo

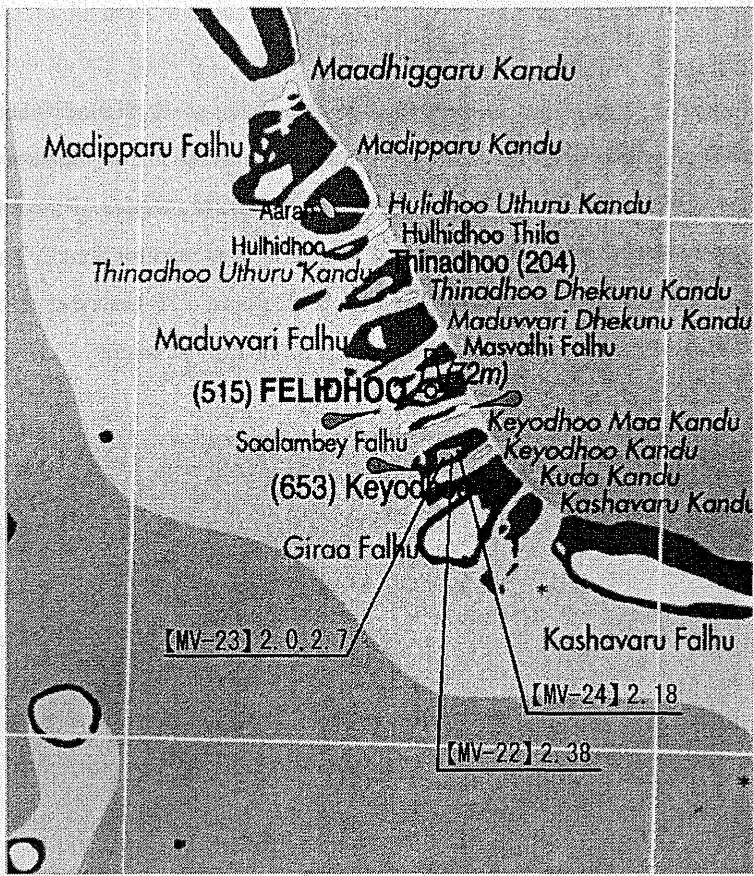


Fig. 5.13 Measured tsunami trace heights (inundation and run up) in Keyodhoo (Vaavu Atoll)

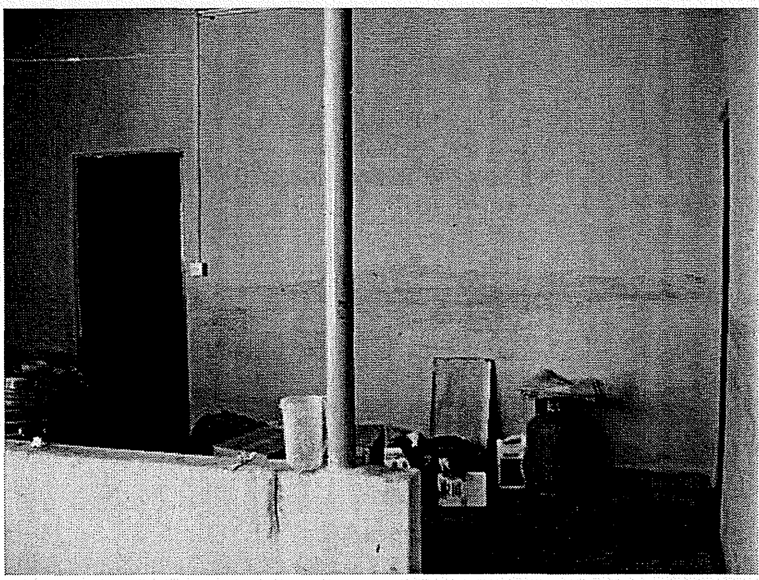


Photo 5.19 Trace of the tsunami on wall in a house (1.08m of water level from the ground)

5.7 Meemu Atoll

Muli is located in the south east of the Meemu atoll, 5 people died and 1 person is still missing. According to eyewitnesses, the tsunami went through from east to west, and the leading wave was the highest. That can be explained from the measured inundation height as shown in Fig. 5.14. The tsunami trace heights were recorded approximately 3m in the east side and 2m in the west. Photo 5.21 shows coastal erosion by the tsunami in west side. It is understand that step of several dozen centimeter is formed.

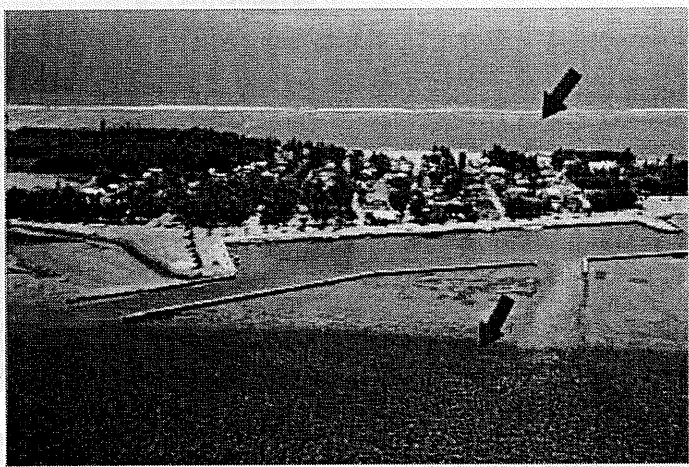


Photo 5.20 Direction of tsunami in Muli

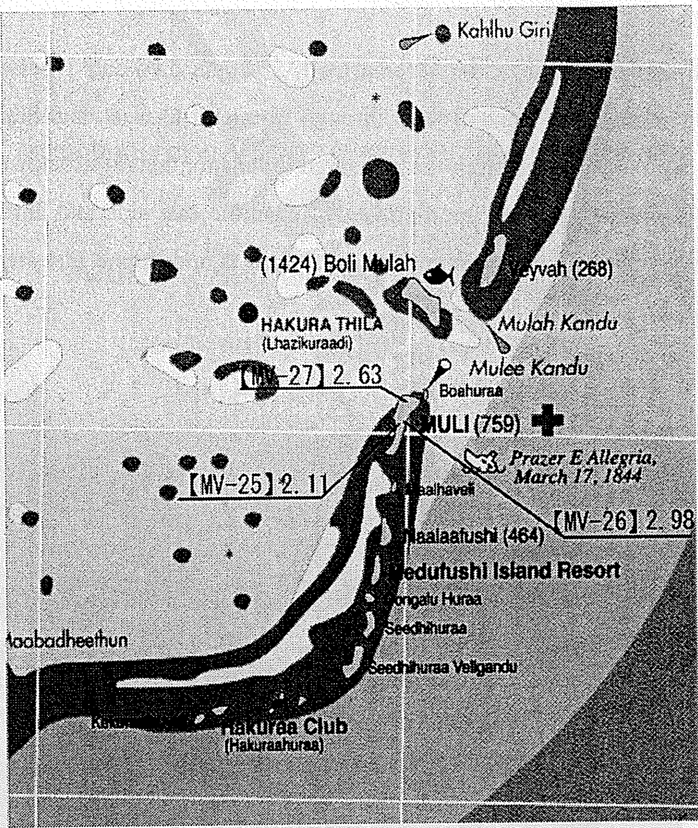


Fig. 5.14 Measured tsunami trace heights (inundation and run up) in Muli (Meemu Atoll)

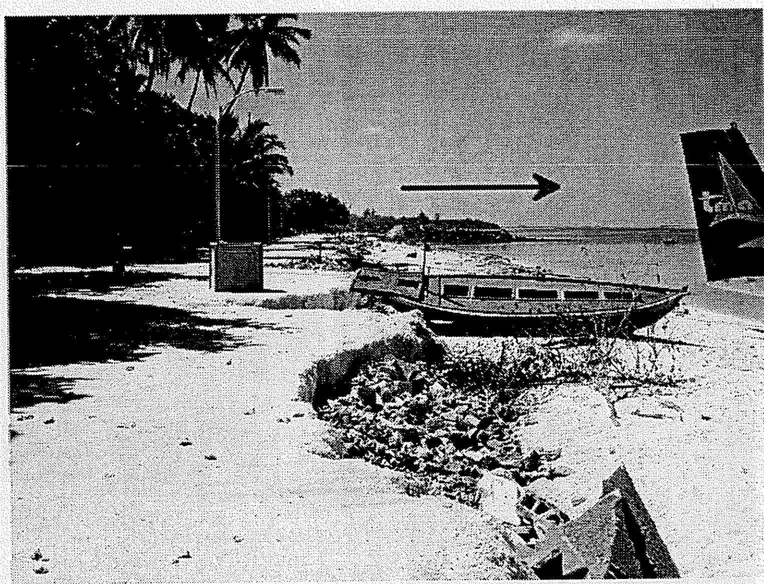


Photo 5.21 Coastal erosion by tsunami in west coast. Red arrow indicates the direction of tsunami.

5.8 Dhaalu Atoll

5.8.1 Ribudhoo

Ribudhoo is in the north-east inside the Dhaalu atoll, there are no deaths in the island. The wave came two times and intruded the east and west sides at the same in Photo 5.22. After that, all over in the island is inundated and the water level repeated up and down during the tsunami coming. Photo 5.23 indicates the tsunami was raised to the line of the breast. In Fig. 5.15, it is found that the tsunami trace heights cross over 3m even if the island is located inside atoll.

5.8.2 Gemendhoo

Gemendhoo, located in the center of east side of the Dhaalu atoll, is one of the island which suffered the most serious damage in the Maldives. 5 people were killed and 3 people are missing in the island. The tsunami went through from east to west (see Photo 5.23), about 3m of tsunami trace heights were investigated at each point as shown Fig. 5.16. Since a lot of houses and physical plants were destroyed in the island (see Photo 5.24), most residents evacuated to a shelter in other island. Photo 5.25 shows damage of erosion by the tsunami. Resident in the island indicates at the ground surface level lower 10cm approximately.

Photo 5.22 Direction of tsunami in Ribudhoo

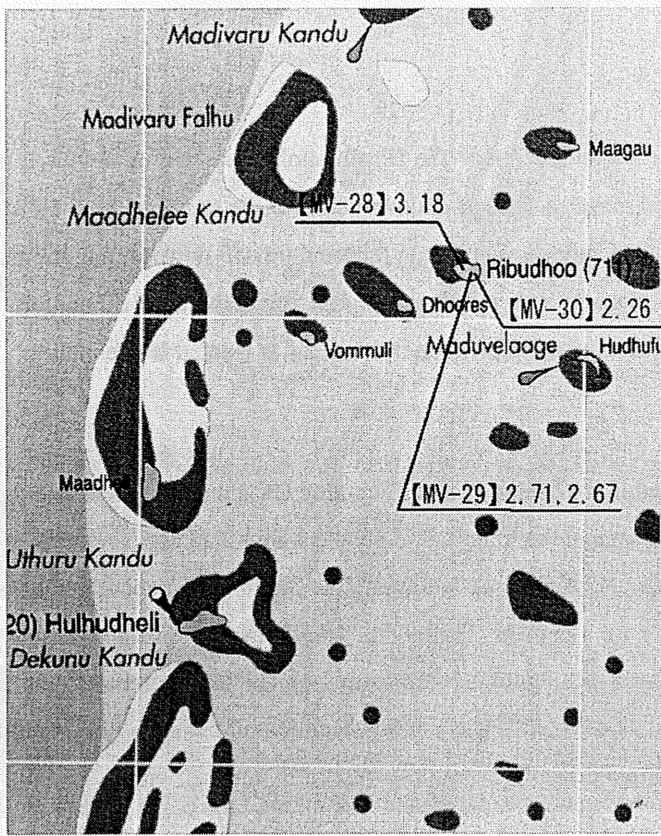


Fig. 5.15 Measured tsunami trace heights (inundation and run up) in Ribudhoo (Dhaalu Atoll)

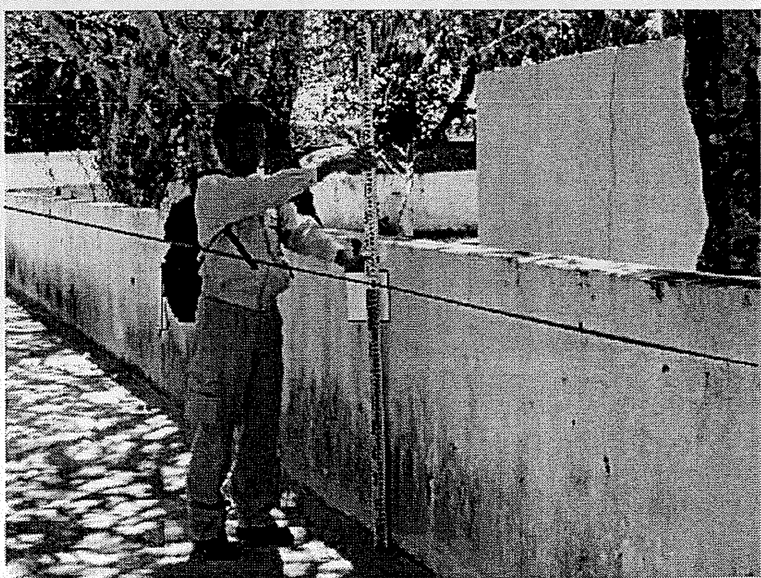


Photo 5.23 Tsunami trace on wall at central of the island

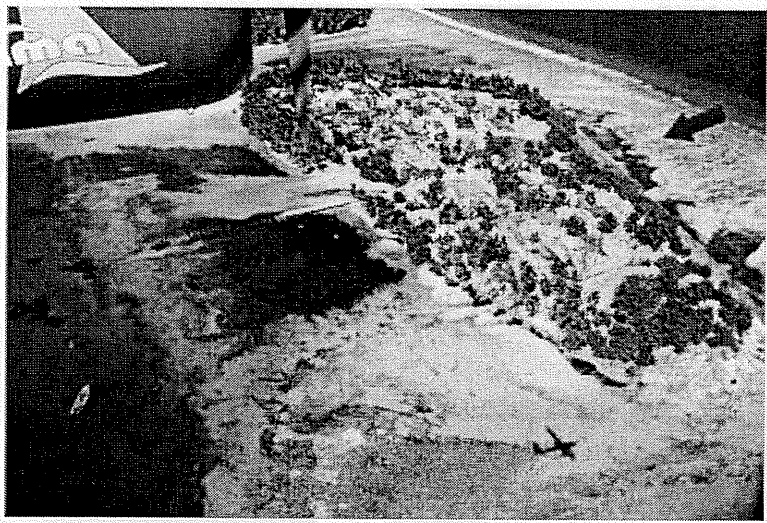


Photo 5.23 Direction of tsunami in Gemendhoo

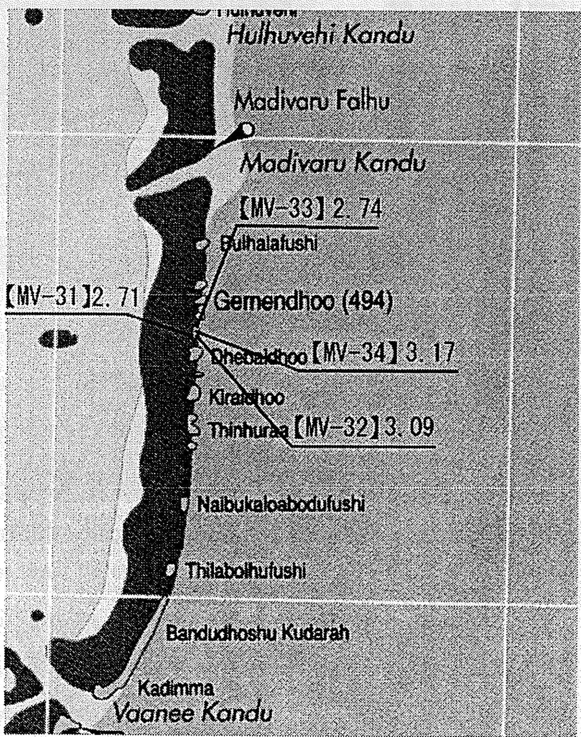


Fig. 5.16 Measured tsunami trace heights (inundation and run up) in Gemendhoo (Dhaalu Atoll)

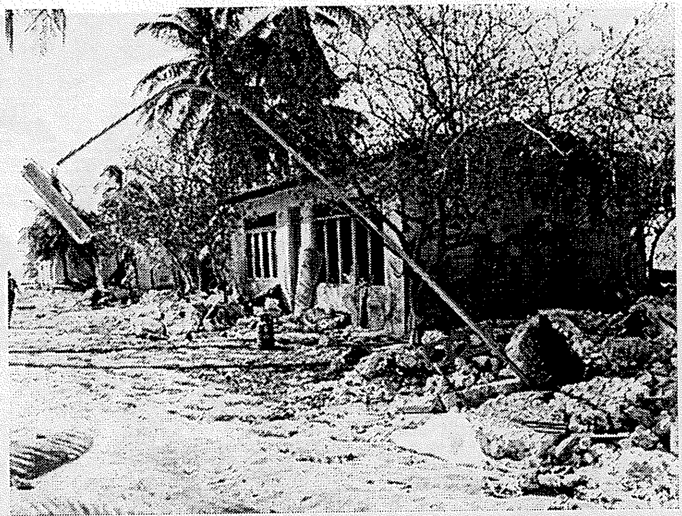


Photo 5.24 Electric light bent by tsunamis

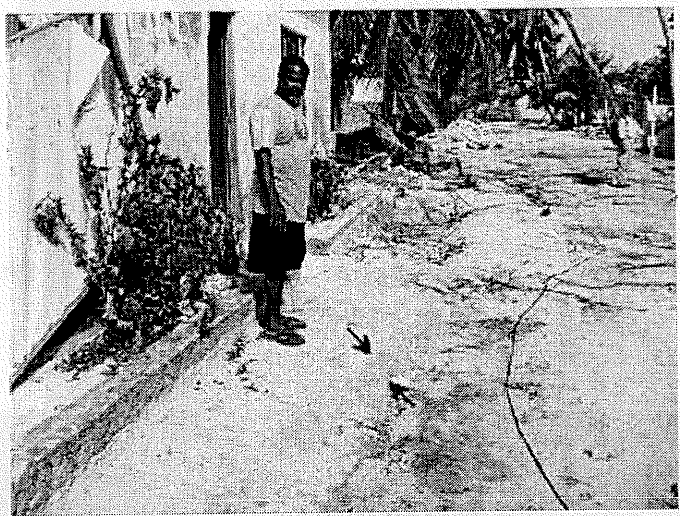


Photo 5.25 Sand erosion by tsunamis. Spacing red arrow indicates thickness of sands eroded by tsunamis.

5.9 Laamu Atoll

Laamu Atoll is one of the heavy damaged atolls in the Maldives by the tsunami (photo 5.26, 5.27). Twenty-two people died, three people are missing and more than 285 buildings were damaged. This is the reason why this atoll was chosen to survey the tsunami inundation heights.

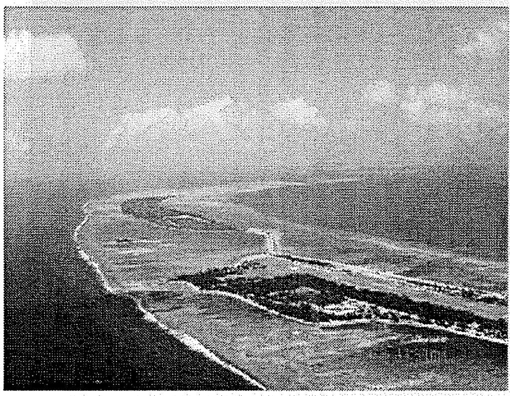


Photo 5.26 Kaddhoo and Fonadhoo Is. in Laamu Atoll

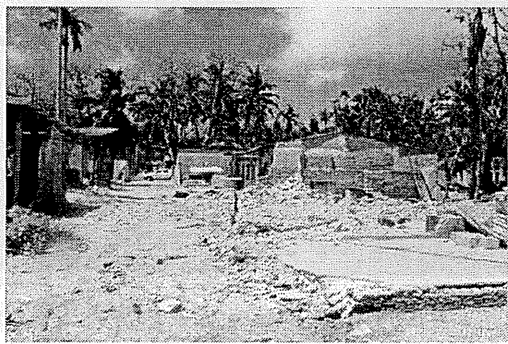


Photo 5.27 Fonadhoo Is.

Tsunami trace heights were surveyed in four islands named Gan, Maandhoo, Kaddhoo, and Fonadhoo. Each island is close to a neighboring island and those are connecting by a road of sand banks. Inundation heights in the islands were 2.08 to 3.22m in the ocean side (east of the islands) and 1.28 to 1.93m in the atoll side as shown in Fig. 5.17. Only the houses at the ocean side were damaged (photo 5.28), particularly in Fonadhoo where four inhabitants died. These results show tsunami attacked from ocean side and progressed to the atoll side, which agreed with evidences of inhabitants and the report of

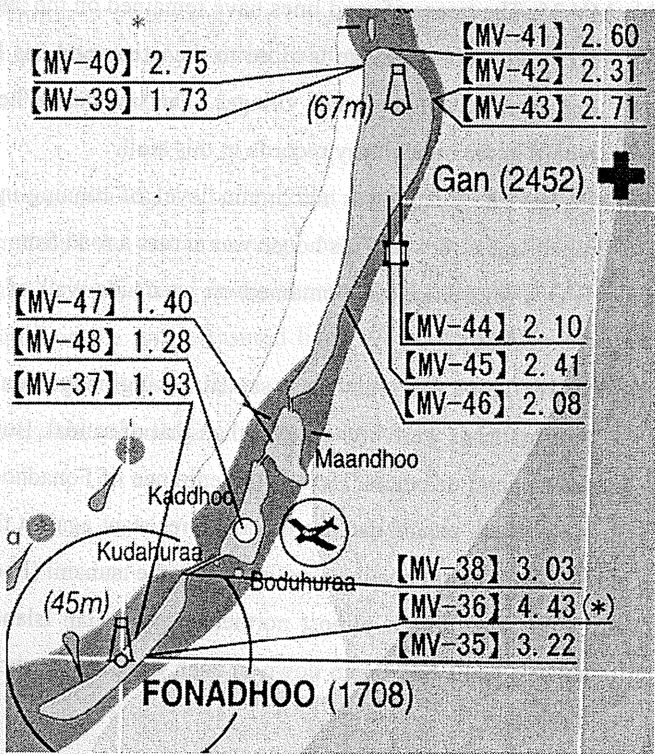


Figure 5.17 Tsunami trace heights in Laamu Atoll

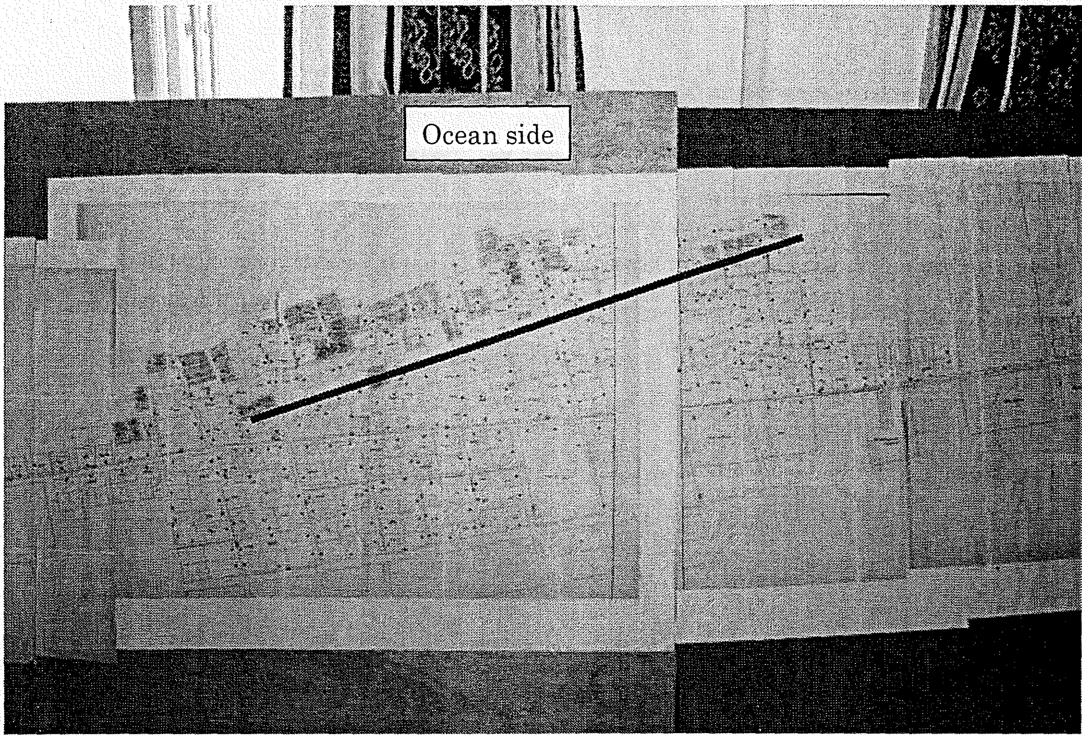


Photo 5.28 Map of completely damaged houses (red marks)

Japanese journalist of Tokyo Newspaper, who visited here on 30th December.

The remarkable notes of each measured point are as follows;

No.MV-35: The traces of sand lines have remained on the inside and outside walls of a house (Photo 5.29). Fonadhoo Village is close to the ocean and has lower density of trees along the coastal line than that of the other villages. The inundation height which was '3.22m' is the highest record in the trustworthy records in this atoll.

No.MV-36: The height was maximum level of running-up water to a house wall based on the inhabitant evidence. This house was across a road from No.MV-35.

No.MV-37: Mud trace had remained on an inside wall of a garage near a coast of the atoll side (Photo 5.30).

No.MV-38: The tracer was beach sandal having hanged on a branch of a tree (Photo 5.31). Some hurt branches were higher level than that of sandal. But these were not confirmed as a trace by the tsunami or others. Here is the entrance of Fonadhoo Island from the road and naked sandy area, which means that there was no resistant against the tsunami. One traffic lane, the road to Kaddhoo from Fonadhoo, collapsed by the tsunami (Photo 5.32).

No.MV-39: This area is almost northernmost in Gan Island and faces to atoll side. Each of three house's walls had fallen down in each direction as showing the tsunami attacked from several directions.

No.MV-40: A plastic bag has been hanging on a branch of tree. This point is on the beach near the No.MV-39.

No.MV-41: ditto

No.MV-42: The tracer here is a plastic bag on a branch too. There are no houses for a long time and there are one road and forests around here.

No.MV-43: This point is close to No.MV-42

No.MV-44: Sandy lines have remained on a house's wall. The height record here was about 50cm lower than that of inhabitant's evidence. She said the water level attained her waist.

The weak wall and house along the roads to each direction in the village were damaged as shown that the water body of the tsunami passed on the roads.

No.MV-45: This record is based on the witness, who is a young worker at an electric power house. He said that this level kept for five minutes. The water level shown by sandy trace was 70cm lower than initial level, and had stayed for two hours.

No.MV-46: Thin sandy line had been on the wall of a house. Residence also said this is a trace. She said that 'these children ran and escaped to west coast of the atoll side when the inundation came'. She was in another island when the disaster occurred.

No.MV-47: Sandy traces had remained on the wall of one facility in a fishery base in Maandhoo. This base was developed in the atoll side and large forest is preserved at ocean side. As pointing to the straight road which led to the east coast, one staff said that the inundation level had inclined, that the level at the east had been high and that in west coast had been low. Second tsunami came from inside of the atoll.

No.MV-48: Airport staffs showed the inundation height at the front of Airport terminal. There are large forests between east coast and this airport.

By comparing of damaged houses in these islands, we believe that a little high ground level and sandy berm and a little large forest reduced the tsunami energy much. Photo 5.38 shows typical situations along the Gan coast. Particularly, ground level is important to reduce that. Fig. 5.18 shows the comparison of ground level elevation on the four measured line. The berms in Gan are higher than that in Fonadhoo which was damaged heavily. It is very important to preserve natural resistances like sand berms and forests against a tsunami.

Photo 5.29 Trace at the No.MV-35 in Fonadhoo

Photo 5.30 Trace at the No.MV-37 in Fonadhoo

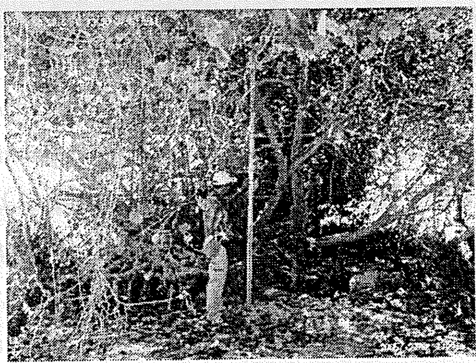


Photo 5.31 Trace at the No.MV-38 in Fonadhoo

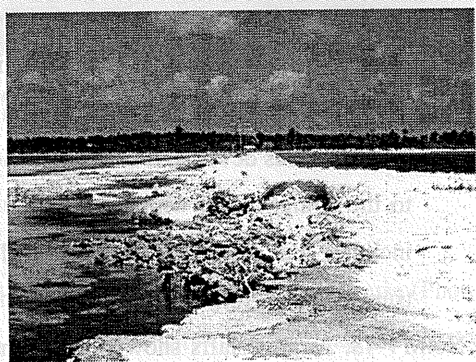


Photo 5.32 Collapsed connecting road

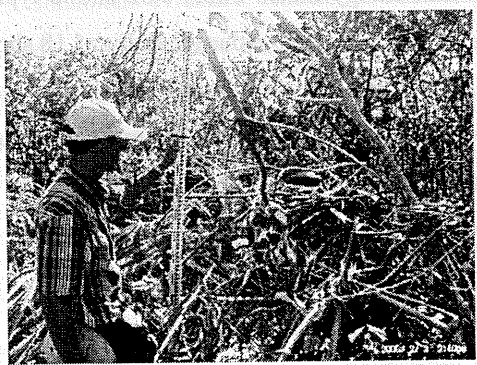


Photo 5.33 Trace at the No.MV-43 in Gan

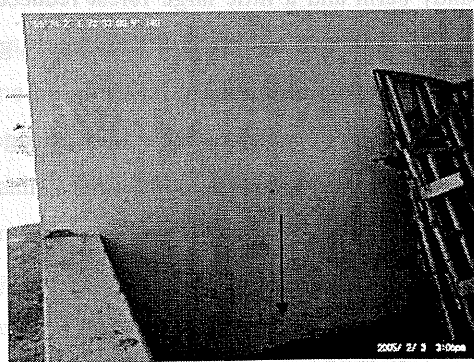


Photo 5.34 Trace at the No.MV-44 in Gan

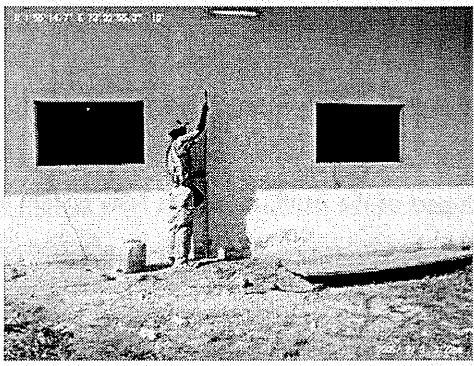


Photo 5.35 Trace at the No.MV-45 in Gan

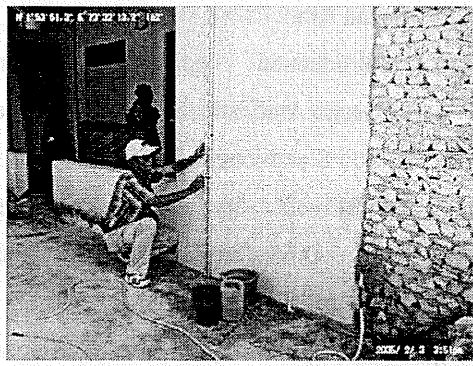


Photo 5.36 Trace at the No.MV-46 in Gan

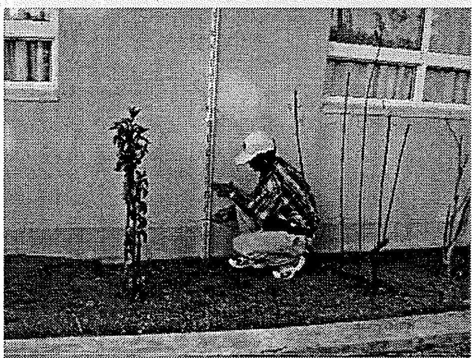


Photo 5.37 Trace at the No.MV-47 in Maandhoo

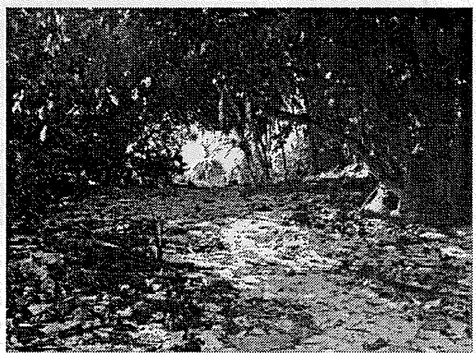


Photo 5.38 Typical shape at Gan coast

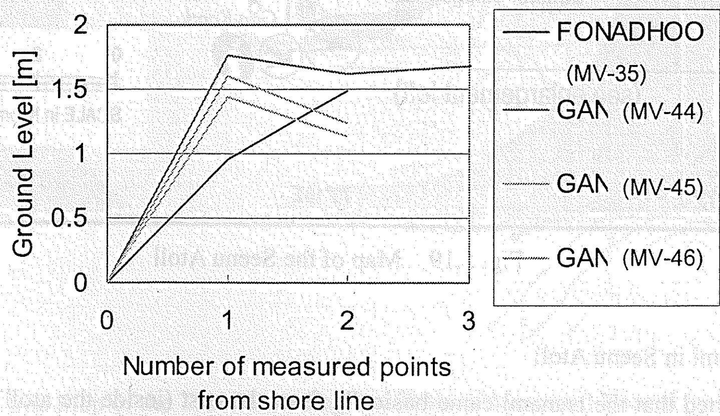


Figure 5.18 Ground level distributions

5.10 Seenu Atoll

5.10.1 Introduction

The Seenu Atoll is the southernmost part of the Maldives and lies between latitude 0° 35' 40" S to 0° 42' 30" S and longitude 73° 04' 30" E to 73° 14' 43" E as shown in Fig. 5.19. It has 4 main gaps of coral reefs. Two of them are located at north part of the Atoll, named as Maa Kandu and Kuda Kandu. Others are located at southeast part of the Atoll, named as Viligili Kandu and Gan Kandu.

The survey team (Dr.Tomita, Mr.Honda and Mr.Hanzawa) visited the Seenu Atoll on 3rd February 2005 and carried out site survey on the west part of the Atoll. The team covered islands of Gan, Feydhoo, Maradhoofeydhoo, Maradhoo and Hithadhoo.

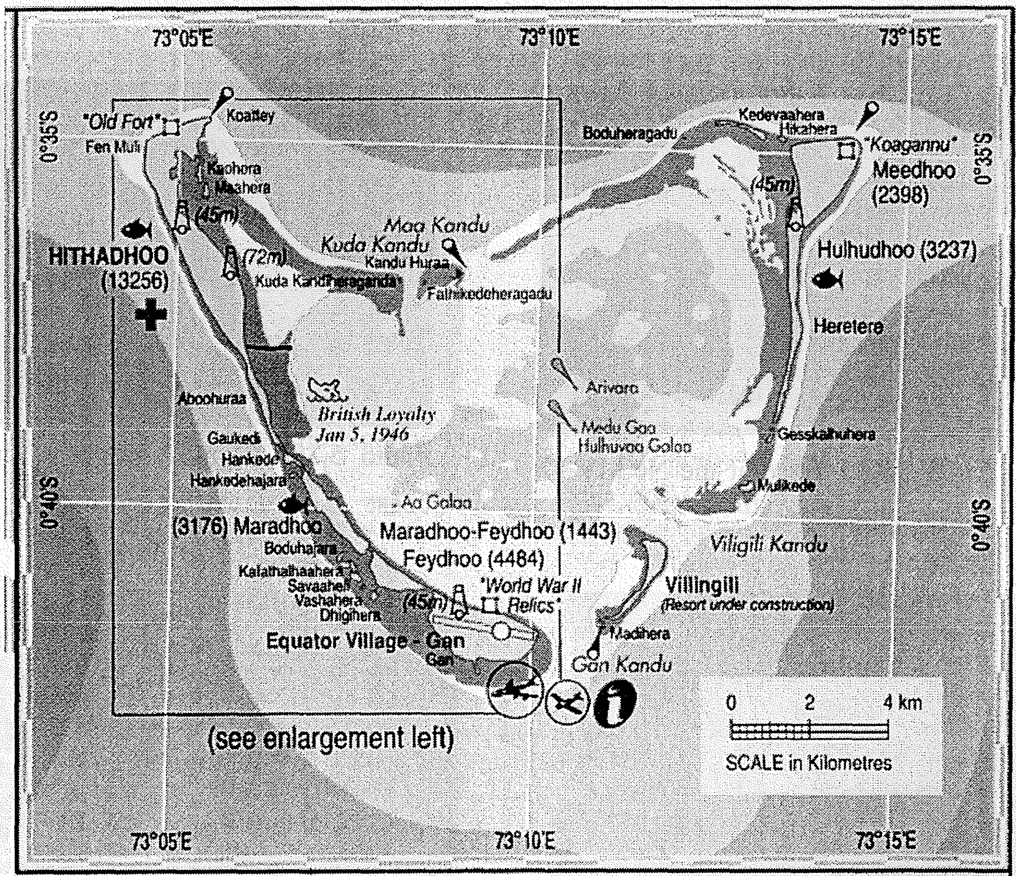


Fig. 5.19 Map of the Seenu Atoll

5.10.2 Tsunami in Seenu Atoll

It is reported that the tsunami came basically from the east (inside the atoll) to the west (open sea) in Seenu Atoll. It seems that the tsunami invaded to the atoll through both north Kandus (Maa and Kuda) and southeast Kandus (Viligili and Gan) based on the interview in the survey area.

Sea level change during the tsunami attack was successfully recorded by Mr. Sugita, Wakachiku

Construction Co., Ltd., at the project site in Hithadhoo. Fig. 5.20 shows the site map and the table of the tide record and Photo 5.39 shows the location of the tide recording. The water levels were measured from the crown of the quay and they were converted to the values above the construction datum level (CDL). The MSL (mean sea level) at the site and the level of the crown of the quay are +2.40m and +0.75m above CDL respectively. Fig. 5.21 shows the sketch of those relations. Fig. 5.22 shows the time series of tide record based on the table in Fig. 5.20.

Date : 26/12/2004

Time	Measurment	Tide
09:25	1,45	0,95
09:26	1,20	1,20
09:27	1,00	1,40
09:28	0,90	1,50
09:30	0,85	1,55
09:32	1,10	1,30
09:35	1,15	1,25
09:39	1,50	0,90
09:41	2,15	0,25
09:43	2,20	0,20
09:44	2,05	0,35
09:47	2,55	-0,15
09:47	1,85	0,55
09:51	2,35	0,05
09:56	3,25	-0,85
10:00	2,20	0,20
10:03	1,85	0,55
10:04	1,85	0,55
10:15	1,70	0,70
10:17	1,25	1,15
10:19	1,60	0,80
10:22	1,70	0,70
10:23	2,15	0,25
10:26	1,60	0,80
10:28	1,65	0,75
10:32	1,45	0,95
10:34	2,05	0,35
10:35	1,95	0,45
10:37	1,95	0,45
10:40	1,95	0,45
10:42	1,65	0,75
10:43	2,05	0,35

Time	Measurment	Tide.
10:44	1,90	0,50
10:45	1,85	0,55
10:48	1,95	0,45
10:49	1,85	0,55
10:51	1,85	0,55
10:53	1,75	0,65
10:55	1,40	1,00
10:58	1,30	1,10
11:00	1,70	0,70
11:05	1,45	0,95
11:08	1,45	0,95
11:11	1,70	0,70
11:12	1,85	0,55
11:14	1,70	0,70
11:18	1,60	0,80
11:21	1,40	1,00
11:25	1,75	0,65
11:30	1,65	0,75
11:35	1,80	0,60
11:40	1,70	0,70
11:45	1,55	0,85
11:50	1,50	0,90
11:55	1,40	1,00
12:00	1,20	1,20
12:40	1,55	0,85
12:45	1,45	0,95
12:50	1,55	0,85
12:55	1,35	1,05
13:00	1,35	1,05
13:05	1,60	0,80
13:10	1,45	0,95

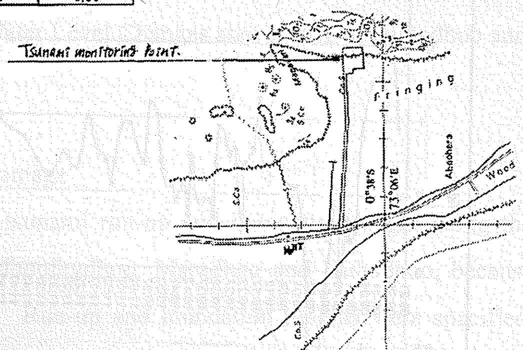


Fig. 5.20 Site Map of the Tide Recording and Table of Measured Record by Mr.Sugita

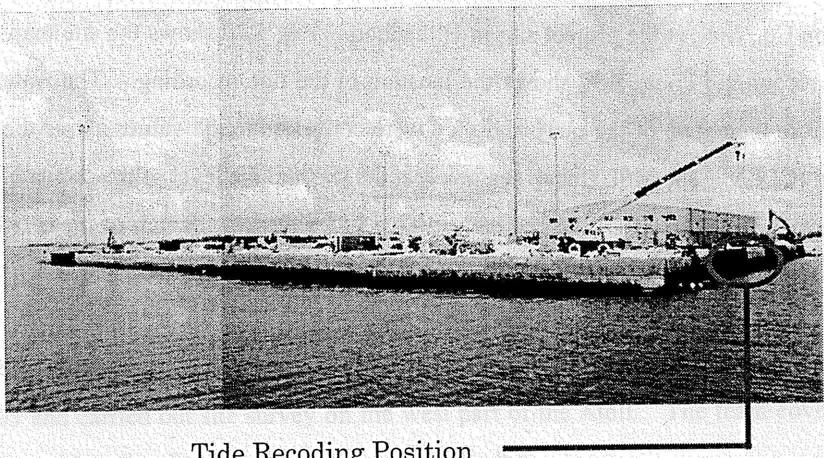


Photo 5.39 Locaion of Tide Recording

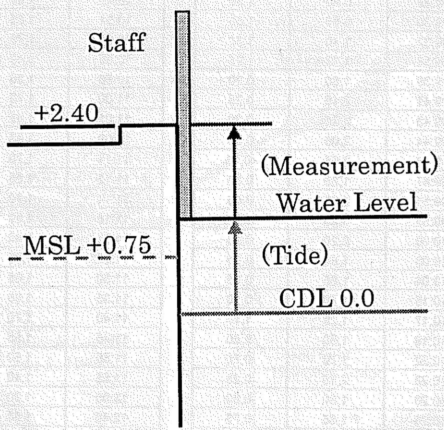


Fig. 5.21 Sketch of Tide Measurement

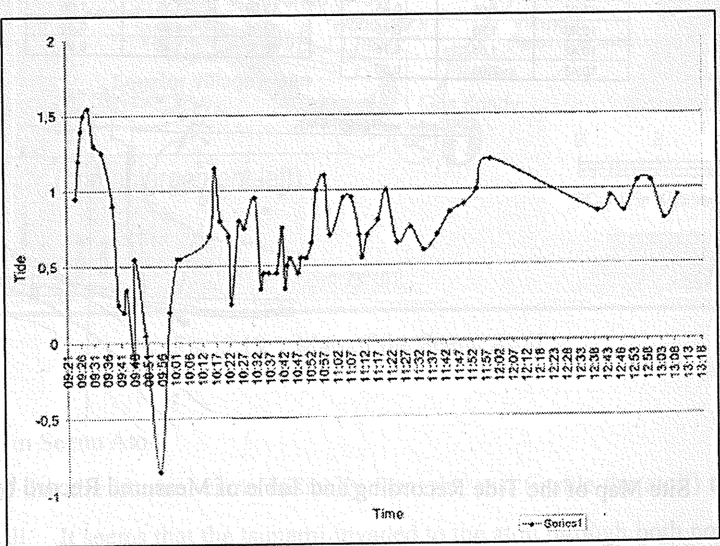


Fig. 5.22 Time series of Tide Record above CDL by Mr.Sugita

Fig. 5.23 shows the water level variation recorded at Wakachiku site in Hithadhoo mentioned above converted to values above MSL together with predicted and actual water levels at Gan Island (0°41' S, 73°09' E) based on web pages of the University of Hawaii Sea Level Center. The maximum water level at Gan reached 0.8m and the minimum -0.5m. As for tide change at Hithadhoo, the maximum reached 0.8m same as Gan, however, the minimum -1.6m far below Gan. The net water level changes affected by the tsunami at up-rush phase at Gan and Hithadhoo are estimated at 1.0m and those at backwash phase are estimated at 0.4m and 1.5m respectively. Large difference observed at backwash phase is considered to be caused by topography difference. According to the interview at Feydhoo, Maradhoofeydhoo, Maradhoo and Hithadhoo, water level change at backwash phase was larger than that at up-rush phase. These observations can be explained and supported by the tide variation recorded at Hithadhoo.

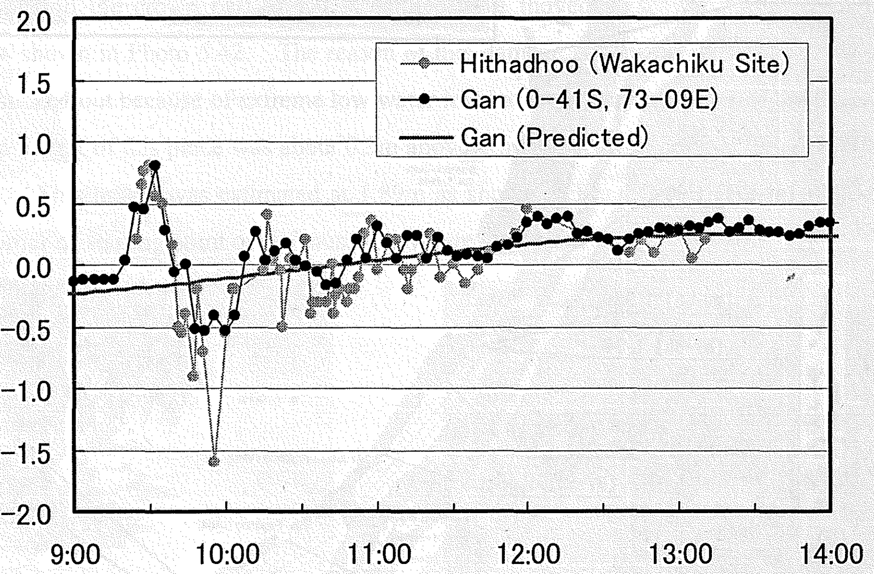


Fig. 5.23 Comparison of Water Level Changes above MSL at Hithadhoo and Gan

5.10.3 Tsunami Trace Height and Damage

The survey team measured the tsunami run-up and inundation height along the east side of survey area of Gan, Feydhoo, Maradhoofeydhoo, Maradhoo and Hithadhoo, because the tsunami attacked from east side in this area. Run-up and inundation heights were specified at totally 11 points based on interview and traces on walls, etc. The results of the survey at those points are shown in Fig. 5.24 as No.MV-49 to MV-59. In the figure the marks "<x" and "x<" mean "smaller than x" and "larger than x" respectively. Those results are discussed again by location with damage observation in following sections.

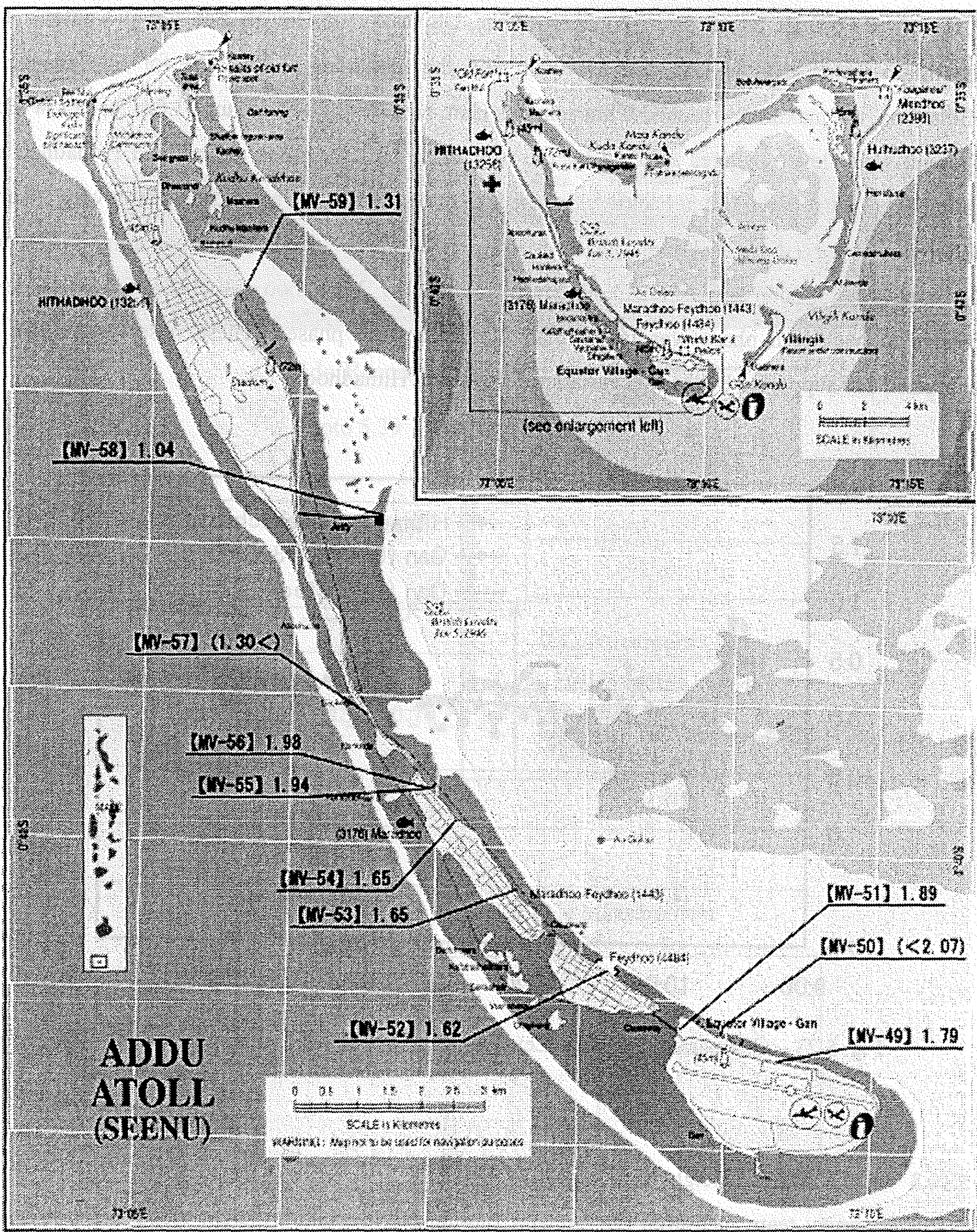


Fig. 5.24 Tsunami Trace Height

1) Gan

The first location of survey in Gan Island was around the construction site of new international airport terminal building. Two-way road is running between the building and seashore. The tsunami at this place considered to have reached about center of the road. This run-up height is estimated at 1.79m as shown in Fig. 5.24 as Point No.MV-49. The seashore in front of the terminal building facing inside the atoll was damaged by the tsunami as shown in Photo 5.40.

The second survey location was the jetty. The crown level of this jetty is 2.07m and the tsunami height did not reach this level as shown in Fig. 5.24 as Point No.MV-50 with the figure of <2.07m.

The third survey location was around the junction of the causeway and the northeast seawall. According to the interview to security officers, the water level rise was observed first at 9:00 am on 26th December. The tsunami came from inside the atoll and three main tsunami waves were observed with interval of 5 to 10 minutes. The first one was the biggest. They also said that the tsunami attack was not like wave but like sea level rise and down. The seawall was damaged by the tsunami and the crown part (super structure) have moved to seaward 1.0m from the initial position as shown in Photo 5.42. The reason of this damage is considered that back fill of the sea wall was sucked out because of extreme low water level at the backwash phase of the tsunami. The inundation height of this place was about 0.3m above crown level as shown in Photo 5.43 by arm of Mr.Sugita. This height was estimated at 1.89m as shown in Fig. 5.24 as Point No.MV-51 that is just the corner of starting point of the causeway where the crown level was measured.

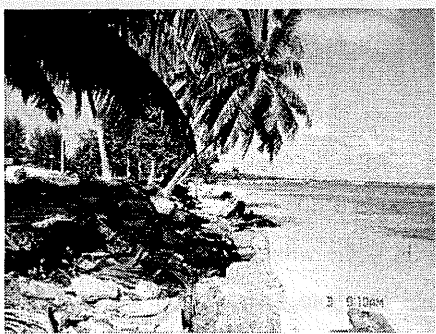


Photo 5.40 Seashore in front of Terminal Bldg.

Photo 5.41 Jetty in Gan

Photo 5.42 Damage of Seawall

Photo 5.43 Run-up Height at Seawall

2) Feydhoo

The survey was carried out around the fishing harbour in Feydhoo. The witnesses said that water level in this area moved up and down for 30 to 40 times within the period of 45 minutes from 9:00am. The water level rose up suddenly and kept high level for about 20 to 30 seconds, then suddenly went down. The highest water level reached just above crown of quay wall shown in Photo 5.44. The run-up height was estimated at 1.62m as shown in Fig. 5.24 as Point No.MV-52. At the time of the minimum water level, the sea bottom of 5m below HWL 1.0m above LWL could be seen, resulting turning over of fishing boat which was under repair in ship yard in Hithadhoo. The detached breakwater made of coral stones was partially damaged by the tsunami as shown in Photo 5.45.

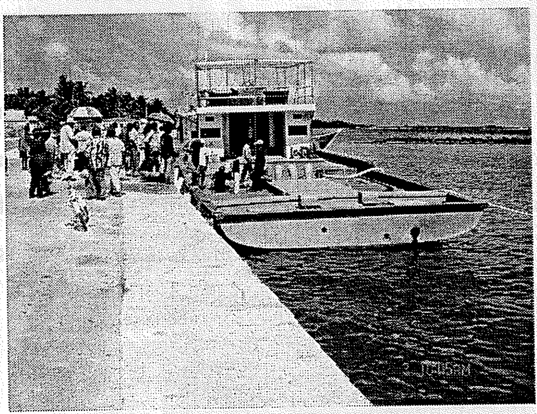


Photo 5.44 Seawall of Fishing Harbour

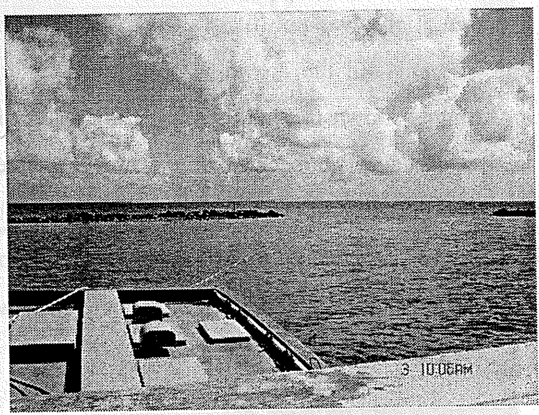


Photo 5.45 Detached Breakwater

3) Maradhoofeydhoo

The fishing harbour in Maradhoofeydhoo was surveyed. The witnesses said that the tsunami reached the crown level of the detached breakwater shown in Photo 5.46 and run-up height was estimated at 1.65m at the seawall as shown in Fig. 5.24 as Point No.MV-53. They said that speed of water level rise was almost the same as backwash.

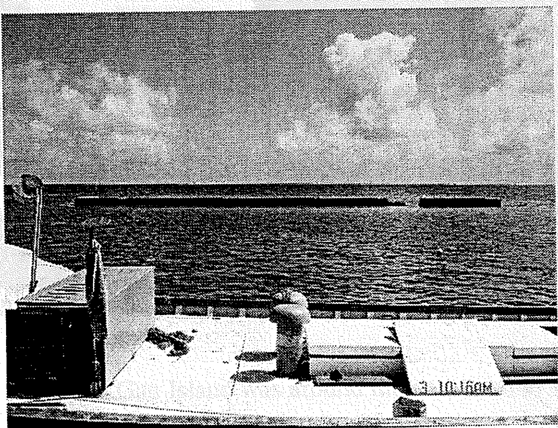


Photo 5.46 Detached Breakwater in Fishing Harbour

4) Maradhoo

Two locations were surveyed in Maradhoo. The first one was fishing harbour. The witnesses said that three waves of the tsunami came to this area and the first one was observed at 9:15am followed by the second and third ones with interval of 5 to 10 minutes. They said that the second one was biggest and the tsunami height was about 1.5m. The inundation height was estimated at 1.65m as shown in Fig. 5.24 as Point No.MV-54. The sea bottom could be seen at the time of minimum sea level and 5 seconds after the minimum sea level was reached then next tsunami came. The seawall in this harbour was cracked and moved to seaward by the tsunami as shown in Photo 5.47. The seawall is considered to move to seaward still now.

The second location of the survey was around the shipyard. The inundation heights were surveyed at two points. The results were 1.94m at Point No.MV-55 and 1.98m at Point No.MV-56 as shown in Fig. 5.24. Point No.MV-56 was ship repair yard and there was the tsunami trace on the wall of house near ship repair yard as shown in Photo 5.48. Photo 5.49 shows the perspective of the wall from seashore.

Photo 5.47 Seawall Damage in Fishing Harbour

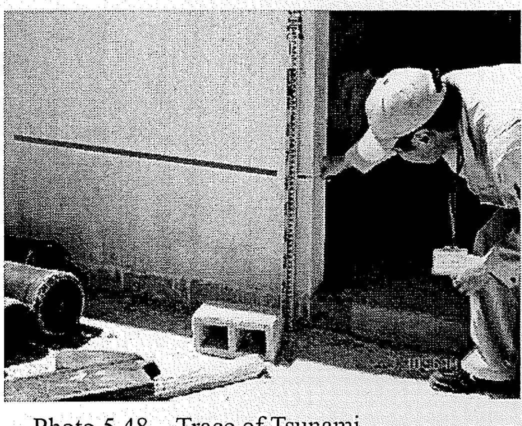


Photo 5.48 Trace of Tsunami

House with Tsunami Trace in Photo

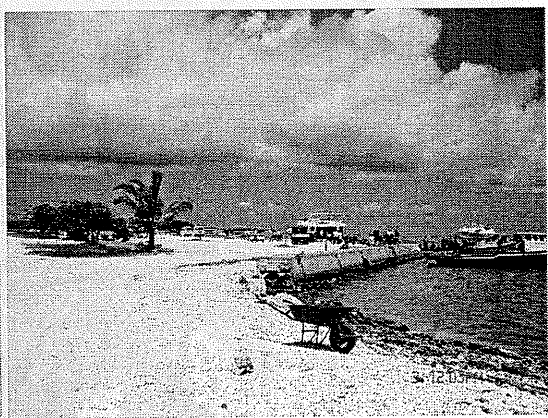
Photo 5.49 Perspective from Seashore

5) Hithadhoo

Three locations were surveyed in Hthadhoo. The first one was around the road located at southernmost area in Hithadhoo, and the inundation height was estimated larger than 1.3m as shown in Fig. 5.24 as Point No.MV-57. Sand beach became like rocky by sand erosion caused by the tsunami.

The second location was the regional port construction (Wakachiku) site as shown before in Photo 5.39 and tide recording was carried out in this site as described before in Chapter 5.10.2. The maximum tsunami height was 1.04m as shown in Fig. 5.24 as Point No.MV-58

The third location was around Hithadhoo Harbour shown in Photo 5.50 and 5.51. The seawall has two crown levels. The tsunami ran over the lower part and reached 15cm below the high crown level. The inundation height was estimated at 1.31m as shown in Fig. 5.24 as Point No.MV-59



Photos 5.50 (Left) and 5.51 (Right) Seawall in Hithadhoo Harbour

5.10.4 Summary

The tsunami in the Seenu Atoll came from east and the maximum water level reached 0.8m above MSL both in Gan and Hithadhoo and the minimum reached –0.5m in Gan and -1.6m in Hithadhoo. The run-up or inundation heights along the islands of Gan, Feydhoo, Maradhoofeydhoo, Maradhoo and Hithadhoo were estimated at 1.5 to 2.0m. The seawalls in Gan and Maradhoo were damaged by the tsunami resulting in seaward movement of crown part. The detached breakwater made mainly of coral stones were partially damaged in Feydhoo and Maradhoofeydhoo.

In addition to the survey results, it is reported by the witnesses that Maa Kandu became shallower because of the tsunami resulting in difficulties in ship maneuvering.

The survey team members wish to express their sincere gratitude to Mr. Sugita, Wakachiku Construction Co., Ltd. for his full support including his offer of tide data recorded at Wakachiku project site in Hithadhoo and to Mr. Mohamad Aslam, Maavahi for his useful information on the Seenu Atoll, his guide to specific place of survey and translation from local language to English. The team members wish to thank all persons concerned in survey area for their useful information on the tsunami.

5.11 Restoration planning in the Maldives

5.11.1 Structural Measures for Hazard Prevention

The tsunami is not the only natural hazard in the Maldives. It is also necessary to consider stormy waves and the storm surge caused by broken waves.

(1) Structural Measures in Low-Lying Areas

To prevent and mitigate disasters from the tsunamis and storm surge, especially in the low-lying areas without evacuation places, structural measures are effective. The structural measures can protect both of human lives and assets. Especially effective tsunami disaster mitigation is to make an integrated defense system which consists of the structural measures to reduce tsunami height and flow velocity and the non-structural measures to support evacuation. For structural countermeasures against tsunamis and storm surge, high structures are necessary, because it is hard to diminish the energy of tsunamis and storm surge by wave dissipation works.

(2) Seawall

Seawalls are commonly used in Japan as the facilities to mitigate the disasters from tsunamis, storm surge and high waves. For high seawalls, on-land gates are additionally necessary to access coasts and harbors. In Male' Island, seawalls were effective to reduce tsunami flooding, because the tsunami above the astronomical tide at the moment which the tsunami came did not overtopped the seawalls badly. The tide level at the moment was around the mean sea level. Since the high tide level was 0.7m above the mean sea level, if the tsunami came at the moment of the high tide, the tsunami flooding may be more severe.

(3) Coastal Rigid Building

Rigid houses and buildings are also effective to reduce tsunami damage behind them. They can work like breakwaters on the land. In the southwest of Sri Lanka, the tsunami trace height was 4.8m behind completely collapsed houses along the coast. On the other hand, it was 3.2m behind the houses with little damage. This is one example that rigid coastal houses contributed to reduction of the tsunami behind them.

Additionally, if the coastal rigid buildings are more than three stories, they can be available for evacuation places.

(4) Evacuation Tower and Building

High buildings are available for evacuation places. Photo 5.52 shows an evacuation tower in Japan. This tower is 5 stories high and has about $220m^2$ in area above the ground floor. It can admit 500 people. It is placed in the area difficult to evacuation by the existence of a river. It is also important to use existing high and rigid buildings for evacuation shelters.

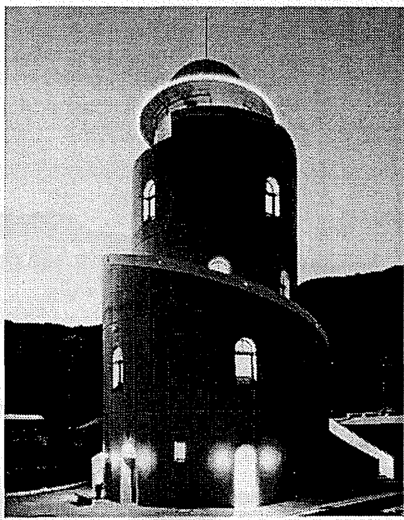


Photo 5.52 Evacuation tower in Kisei-cho, Mie prefecture, Japan

(5) Evacuation Terrace

Okushiri Island suffered severe damage by the 1993 Hokkaido Nansei-oki Earthquake Tsunami. The tsunami of 10m high attacked the south part of the island. After the tsunami, high seawalls were constructed along the coast to protect coastal low-lying areas. However, a fishery port was out of the seawalls to keep its fishery function. For evacuation of the persons working at the port from tsunamis, a new terrace was constructed as a tsunami shelter. The terrace was usually used for fishery activities.

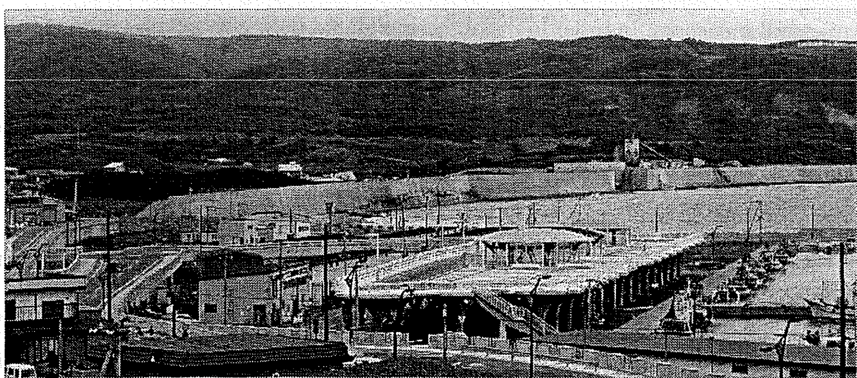


Photo 5.53 Tsunami evacuation terrace

(6) New-type Seawall

In the Maldives, high waves and storm surge are also natural hazards as well as tsunamis. The wave height can be reduced by wave dissipation works more easily than tsunamis and storm surge.

Photo 5.54 shows a new-type seawall constructed in Japan. This seawall has a buffer zone to prevent coastal inundation due to overtopping waves. The waves overtopped the front face of the seawall can permeate a buffer zone installed in front of the original seawall.

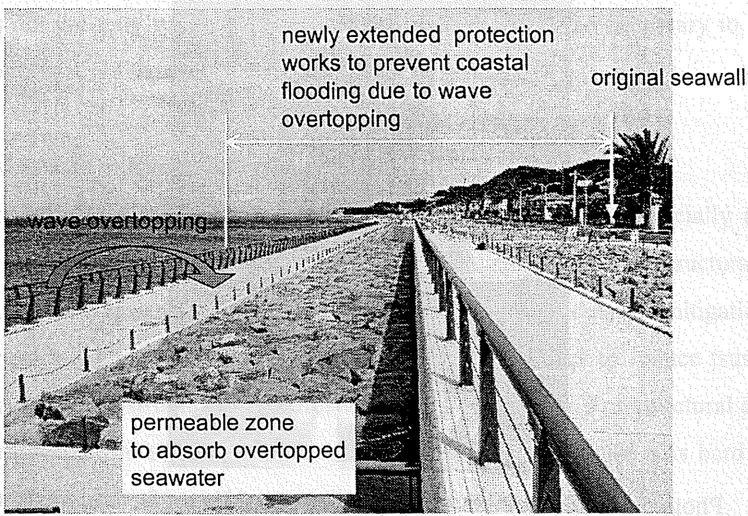


Photo 5.54 New-type seawall

(7) Defense System

The structural measures can provide disaster prevention for specified hazards. However, for the hazards exceeding the specified level, which can happen in the future, the structural measures couldn't be necessarily effective in preventing damages. At that time, non-structural measures are needed to prevent the loss of human lives. Therefore, to prevent and mitigate the losses of human lives and assets, it is important to make an integral defense system which combines the structural and non-structural measures. In order to make the integrated defense system, we need to

- understand natural hazards in the target area with analyzing historic records, monitoring sea states and conducting numerical simulations, and
- understand the vulnerability of the community with evaluation of damage due to the natural hazards.

For the damage evaluation, it is necessary to evaluate the defense performance of structural measures. If there is less performance to prevent damages in the structural measures, we need to extend the performance of the structural measures or have the non-structural measure to save human lives, i.e. a supporting system of evacuation.

The consideration of quick restoration is also important. Some infrastructures and facilities such as a power plant are indispensable for restoration and it is, therefore, necessary to avoid severe damages of them to do some countermeasures. For example, a power plant in an airport is one of the most significant facilities. If it is inundated and does not function, the airport cannot be reopened quickly. In this case, one of the defense measures for quick restoration is to set power generators up high or to make the power plant to watertight structure, depending on the situation of the airport. We need to select and combine suitable structural and non-structural measures to mitigate disasters.

5.11.2 Education and Evacuation

Even if some large facilities are constructed along the coastline, we cannot expect that the tsunami is always/perfectly blocked by the facilities. Evacuation of the residents and tourists is necessary to save their lives. The following countermeasures are required to make a safe evacuation.

(1) International warning system

The large earthquake perhaps may occur far from the Maldives. The department of meteorology in the Maldives has to receive the accurate information on the earthquake and the tsunami as soon as possible.

(2) National warning system

The residents and tourists in the Maldives may not feel the strong earthquake, because the epicenter of earthquake is distant from the Maldives. Thus, no one be cautious about the tsunami if they cannot receive the tsunami warning. The department of meteorology in the Maldives has to dissemble the information to the island offices, mass-media and all residents and tourists to urge them to evacuate. This is difficult but important and essential for tsunami hazard prevention.

(3) Adequate facility for evacuation

In the Maldives, there is no mountain. Thus, some refuge structure, e.g. solid building and artificial ground, is required for the evacuation. Note that a refuge structure should be constructed for not only the hazard prevention but also the ordinary activities of the residents or tourists, because the hazard is not occurred so frequently and the daily use of the facility is desirable for the maintenance. However, the aim of the facility should be written clearly on/near the structure not to forget the hazard risk.

It is also important to strengthen the houses and walls. In some islands, the mosque kept without damages, although many houses were washed away. This indicates that the solid structure is not destroyed by tsunami. If many houses near the coast are not destroyed and remain there, the tsunami flow inside the island becomes weak and the whole damage is expected to decrease.

(4) Disaster education

The residents have to evacuate onto a proper location by themselves. They should be educated in the following items.

1. Fundamental knowledge on earthquake and tsunami
    - earthquake distribution in the world, plate tectonics
    - probability of aftershocks
    - propagation speed of tsunami

- initial motion of tsunami (flood or ebb)
- wave number of tsunami
- the fact that tsunami height is strongly affected by the local topography

2. Fundamental knowledge on earthquake and tsunami for the Maldives
   - Great earthquake may occur on the subduction zone, the most active one near the Maldives locates at the west of Sumatra. In such case, tsunami arrival time at the Maldives may be 3 hours after the earthquake, then, the residents may have enough time to evacuate.
   - Of course, there is the exception. If the earthquake occurs near the Maldives, the tsunami arrival becomes rapid.
3. The appropriate evacuation route
   - to high land
   - to offshore (If they are on the sea, they should not return to the island.)

In addition, it should be emphasized that the most important countermeasure is not to forget the hazard risk. The hazard education should be carried out at not only school but also public space. In Hawaii and Papua New Guinea, the article on tsunami (when they should take care, how they should act under the tsunami warning) is published on a telephone book. A sign showing the evacuation route constructed in the United Sates and Japan plays not only the original role but also the role of the publication of the risk. A mass media has also important role to pass our experiences to the next generation.

The tsunami countermeasures are summarized as follows:

- Facility construction to prevent tsunami
- Facility construction to evacuate from tsunami
- Preparation of tsunami warning system
- Hazard education

The above measures should be combined, depending on the circumstances.

5.11.3 Future Plan

In the 26/12/2004 Indian Ocean Tsunami, the tsunami height was similar to the crown height of the quaywall of Male'. Then, the quaywall and seawall worked effectively and Male' city was saved from the heavy disaster by the dam-effect of quaywall and seawall. However, there were some lucky factors in this event.

1. The tide level was not high at the arrival time of tsunami, but approximately the mean level.
2. Because the incident direction of the tsunami was east and Male' Island is sheltered by Fulhule

Island in the east direction, the tsunami height possibly decreased to some extent in Male'.

3. The tsunami arrived in the morning, so the residents maintained their composure.

Thus, the tsunami risk assessment is required to check the safety level of Male' against tsunami, by varying the time, the season, the location of tsunami source area and so on in the tsunami numerical simulations.

The 'Safe Islands Programme', future plan of the Maldives, seems very rational and effective. However, the location and the ground level of the safe island and the height of the quaywall should be carefully determined based on the risk assessment.

We cannot become perfectly safe against tsunami by any means, by any investments. The Maldives should determine the target safety-level and select the combinations of the countermeasures, considering the cost performance and the living comfortability. This decision should be conducted by the government of the Maldives. To support this decision of the government, the experts of coastal engineering and hazard prevention should be educated.

Chapter 6 Field Research on Social and Physical Impacts, and Responses in the Affected Areas

6.1 An Overview

6.1.1 The Indian Ocean Tsunami Disaster and Social Research

The Sumatra Earthquake and Indian Ocean tsunamis of December 26, 2004 have been described as creating one of the "worst disasters" in recent history. Twelve countries around the Indian Ocean were affected, but Indonesia, Thailand, India and Sri Lanka had the largest numbers of deaths and displaced people.

The affected areas are quite different demographically, politically, historically, economically, socially and culturally. To grasp the damages and influences caused by the earthquake and tsunamis, and the immediate responses of the locals, visitors, administration offices, social research teams were organized and sent to the devastated areas in Indonesia, India and Sri Lanka. This was the first joint field research project supported by the Grant-in-Aid for Scientific Research of Ministry of Education, Culture, Sports, Science and Technology, Japan; combining natural scientists, engineers and social scientists to work together for the analysis of the capacities and vulnerabilities of affected communities.

The research participants, with the backgrounds of anthropology and area studies, have been studying politics, economy and culture both in national and in local contexts. With their local language skill, they have been keeping long term relationships with the societies. In spite of rather short periods of field research, with their expertise, they have conducted productive research in each site. These research trips are only the first steps in the long term social monitoring research.

6.1.1 Field Research on Socio-cultural Aspects of Disasters

Disasters cause harm and damage to people, property, infrastructure, economies and the environment. Natural disasters can be easily understood when considered as the subject of scientific and technical research, but there is still a low level of recognition of such disasters as a matter which encompasses the human and social sciences. Although a natural disaster is something that results from a complex interaction of forces generated by the natural world, technologies created by humankind, and society and culture, the fact is that much of the research related to disaster involve little surveillance study of the corresponding social processes.

Disaster researches focusing on socio-cultural aspects encompass a wide range of subjects, including the human perception of risk, social relationships, religion, and ethics which act upon disaster management organizations, the self-implemented disaster prevention/reduction activities of a region's people, the daily lives of disaster victims living in temporary housing or reconstructed housing, the causes of the disasters, rescue and reconstruction support activities, the processes of remembering and recording the disaster, etc.

In recent years we are seeing research that approaches the social and cultural aspects of the disaster-related processes of preparation prior to disaster occurrence and preparedness when warnings are issued, emergency response before and after disaster occurrence, and restoration and reconstruction after a disaster. In Japan, the Great Hanshin-Awaji earthquake Disaster of 1995 served to create a strong awareness of the complex, escalating chain of damage brought about by a disaster due to advancements in scientific technologies and the progression of urbanization. This new awareness led numerous social scientists to launch disaster-related research.

6.1.2 Regional Characteristics and Field Research

When attempting to apply leading technologies and programs related to disaster management (risk reduction, emergency response and restoration/reconstruction) unmodified to a developing country or a developing region, the problem of understanding different cultures surfaces. At present, the development of disaster management systems, relief activities at the time of disaster, and post-disaster support for restoration and reconstruction, are being conducted at the international level. Through the establishment of a system for collaborative research by disaster-prevention researchers and researchers specializing in anthropology/area studies, it may well be possible to contribute to future international disaster reduction efforts.

Needless to say, the collection and analysis of data related to disasters in the past are also needed. This data can come from reports issued by disaster response organizations and government administrations, research results released by various research organizations and activity organizations, including NGOs, mass media reports, historical records and stories about disasters, talks with disaster victims about their experiences, etc.

Furthermore, it is also vital to study the disaster management activities conducted by the members of the affected society. It is important to conduct field research that goes beyond introductions of disaster reduction technologies; research must also include the reactions to, opinions of, and implementation of these technologies, the work processes involved in establishing disaster management systems, the reactions and opinions of participants in disaster prevention workshops, relief activities at the time of disaster occurrence and the reactions of the victims to these activities, the restoration and reconstruction processes, and in regard to buildings and structures, not only earthquake-resistant building standards, but also how, within the various social relationships and economic background of the region, residential housing is actually being constructed utilizing the knowledge and skills of local masonry workers. Through such research, we can start to identify some specific social or cultural attributes that could be important for disaster reduction research. Otherwise, it would not be possible to understand the socio-cultural context within which any engineering or any other technological solution might be applied.

6.2 Impacts of the Earthquake and Tsunami upon the Society of Aceh, Indonesia

6.2.1 Introduction

The December 2004 Sumatra earthquake led to much devastation in northern Sumatra and the rest of the perimeter of the Indian Ocean. One of the areas most affected by the tsunami was the province of Nanggroe Aceh Darussalam, Indonesia, which is located at north of Sumatra Island.

Immediately after the tsunami, large volumes of both support personnel and support goods rushed into Aceh. By the time we visited Aceh for the field survey in mid February 2005, six weeks after the tsunami, it seemed that the general situation was gradually shifting from emergency to reconstruction and rehabilitation. Government officials were commanded to report to their offices by 15 February, and relocation of displaced people from field camps to temporary housing was planned to start on the same day. On the other hand, some tsunami victims had already started construction work towards resettling in their original places, without waiting for the government to disclose its master plan for reconstruction.

It is necessary to have a well-considered master plan before reconstruction starts, in order to build disaster-resistant cities and countryside areas in Aceh, and for that purpose it is highly important to investigate the strengths and weaknesses that Aceh society showed in encountering the tragic disaster.

Besides physical reconstruction, attention should also be paid to the recovery of cultural assets, because the recovery of collective memories plays no less important a role in the rehabilitation and reconstruction of a community.

The main purpose of our field survey was to investigate the damages to the local society incurred as a result of the December 2004 earthquake and tsunami, particularly in Banda Aceh city and its adjoining areas, and the reactions of the people toward the tragic experience. Interviews with tsunami survivors as well as with government officers and aid workers were undertaken to determine the conditions and manner of their coping mechanisms related to the tragic experience of the tsunami, including the systems that supported the victims. During the field survey, information relating to the damage to cultural assets was also gathered.

6.2.2 Overview of Damage in Aceh by Region

The province of Aceh is geographically divided into four areas: (1) Banda Aceh and its adjoining district, (2) the Southwest coast region, (3) the North coast region and (4) the Interior region. The details of number of victims by region are shown in the table below.

Table 6.2.1 Number of tsunami victims in Aceh by region

	Aceh Province	Banda Aceh & adjoining	Southwest Coast	North Coast	Interior
Population	4,263,603	550,532	953,377	2,250,017	509,677
Dead	100,258	62,273	29,164	8,596	225
Missing	129,549	123,492	3,858	1,922	277
Displaced	417,124	150,858	120,125	140,932	5,209

(Source: Disaster Countermeasures Provincial Office, 24 January 2005)

(1) Banda Aceh and its Adjoining District

Banda Aceh is the provincial capital and the largest city in Aceh. It is located at the northwest tip of Sumatra Island and is surrounded by Aceh Besar district. Banda Aceh suffered a direct hit from the December 2004 tsunami. The residential zone, spread between the coastline and the city centre, was completely destroyed. The commercial zone and government offices escaped total destruction but were damaged badly by the flood. Most of the dead and missing people in Banda Aceh came from the above mentioned zones.

There lay a large portion of land in the hinterland of Banda Aceh city centre which the tsunami did not reach. Iskandar Muda airport, 17km away from city centre, is located in that zone. Land transportation between Banda Aceh and Medan, the capital of North Sumatra province and the largest city in Sumatra Island, sustained minor damage. Emergency relief, both people and goods, arrived in great volumes in the hinterland of Banda Aceh, and this area became the base for emergency relief activities in the region.

(2) The Southwest Coast Region

The Southwest coast region, which consists of the districts of Aceh Jaya, Aceh Barat (West Aceh), Nagan Raya, Aceh Barat Daya and the island of Simeulue, was closest to the epicenter of the 2004 earthquake which triggered the tsunami. The only road accessible by car ran along the coastline and a number of towns and villages are located along it.

The tsunami not only destroyed towns and villages in the region but also severed the road and destroyed some bridges along it. Towns and villages were totally isolated and accessible only by boat or by helicopter. This caused much difficulty in correctly ascertaining the damage in the region. It also caused much trouble for aid workers who undertook their activities in the region.

(3) The North Coast Region

The North coast region consists of the districts of Pidie, Bireuen, Aceh Utara (North Aceh) and Aceh Timur (East Aceh) and the city of Lhokseumawe. Traditionally the rice-growing centre, the region has the largest population density in Aceh. Natural gas yielded in Lhokseumawe uplifted the importance of the region economically and strategically. The region is also important from the viewpoint of land transportation in Aceh. The road connecting Banda Aceh and Medan runs through the North coast region. Towns and villages in the Southwest coast region could only be reached by the road through the North coast region if the road along the Southwest coast was destroyed.

Except on several fishing villages in this region, the tsunami did not seem to inflict severe damage, especially in comparison to other regions in Aceh. Nevertheless, the local society was much affected by the tsunami because survivors from the Southwest coast flocked into the towns and villages in the North coast region. Moreover, the perception that the region was less-affected by the tsunami discouraged relief aid from reaching the region. It could cause future social uncertainties if relief aid continued to concentrate in other regions only.

6.2.3 Initial Damage to Building, Physical and Social Infrastructure

First of all, it should be emphasized that the scale of the disaster in Aceh was unimaginably large. A vast expanse of territory was affected by the tsunami, though the heavy damage was concentrated in four regions: Banda Aceh, Aceh Besar, Ache Jaya and West Aceh. The total number of dead and missing persons in Aceh exceeded 200,000. Many bodies had to be buried before identities could be confirmed. A large number of victims were still "missing", as the tsunami had possibly swept away their bodies.

In the initial stage of disaster relief, it is very crucial to grasp the overall situation in determining the distribution of emergency relief. Initial damage to the buildings, physical and social infrastructures made it difficult to gather and share information.

6.2.3.1 Building Damages

(1) Distribution of Building Damage due to Seismic Ground Motion

A field survey was conducted from February 12 to 16, 2005 in mainly Banda Aceh. The method of the survey was to record the locations of damaged buildings using a camera with GPS (Global Positioning System) and a mobile GIS (Geographic Information System).

In Banda Aceh, which is about 250 km way from the epicenter, it was reported to have recorded IX of MMI seismic intensity by USGS[1]. According to interviews with inhabitants, tsunami that engulfed Banda Aceh reached the urban area about 30 minutes after the earthquake. As to building damage caused by seismic ground motion before the tsunami attack, complete collapse, which is a damage pattern that accompanies loss of surviving space and strongly involves human casualties, were focused on. As a result, the location and building attributes (usage,

[1] USGS: http://earthquake.usgs.gov/, (2005.4)

structure type and number of stories) of 13 collapsed buildings were recorded. The distribution of completely collapsed buildings and each detailed collapsed pattern are shown in Figure 1. Figure 1 shows both area of influence of the tsunami summarized by OCHA[2]; and city structure map developed by Nagoya University[3]. Completely collapsed buildings were all of RC frame structure, 11 buildings were three- to five-story structures. According to a researcher of the Syiah Kuala University with whom jointed this survey, there was no building higher than six-stories in Banda Aceh. Even though this is a result of a survey in a limited area, the feature of distribution of complete collapse was that it was concentrated in the center part of the city and the office area where the Great Mosque is located.

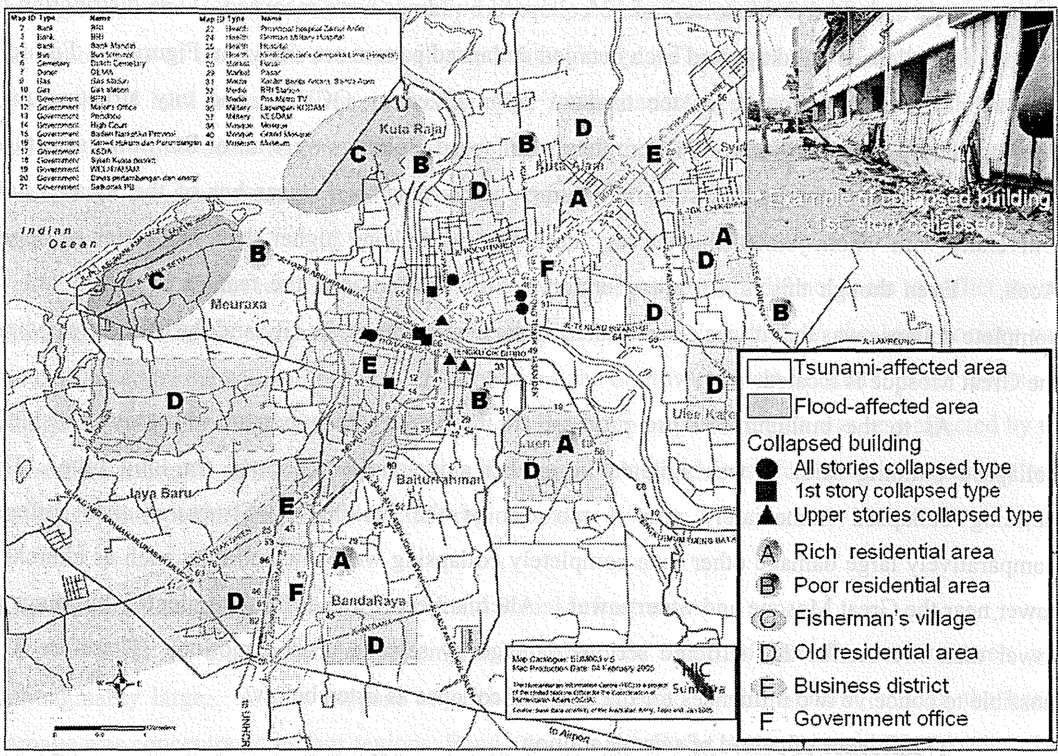
As to the building collapse process, an interview with a person who stayed inside a collapsed building said: "I was agitated because a slow quake continued for long time. The building collapsed immediately after I ran out of the building". Structures that suffered comparatively large damage other than completely collapsing were towered type such as churches, tower near the Great Mosque and water tower. Alternatively it was difficult to identify buildings of lower than two stories that suffered serious damage by seismic ground motion. Therefore it is possible to conceive two influences for the cause of collapse as listed below.

1) Influence of period of seismic motion
2) Influence of the long duration of the quake

However, there remain many buildings higher than three-stories that look normal in terms of appearance. It is possible that there was a large influence of poor earthquake proof quality of the collapsed buildings and ground characteristics of the site.

From the result of above analysis, it was revealed that buildings collapsed due to the earthquake before the arrival of the tsunami. Collapse of buildings may cause failures to escape due to rescue activities for trapped people in the building, and obstacles on the evacuation route. When such buildings are mid- to high-rise, problems of lost evacuation centers may occur. To prepare against tsunami disaster, it is especially important to ensure sufficient seismic performance of buildings and appropriate location for mid- and high-rise buildings which should serve as evacuation centers. In addition, some key issues in the future are to evaluate tsunami force correctly to such important buildings and to establish a design method that takes tsunami load into consideration.

2 The Human Information Centre, OCHA: Map Catalogue, SUM003 V.5, 2005. 2
3 Graduate School of Environment Studies, Nagoya University, Investigation Report of 2004 Northern Sumatra Earthquake, pp.39, 2005.3



Source: OCHA (2005), Nagoya University(2005)

Figure 6.2.1 Distribution of completely collapsed buildings due to seismic ground motion

(2) Distribution of Buildings Damaged by Tsunami

As to building damage caused by the tsunami in Banda Aceh, a distribution of buildings washout ratio were estimated using satellite imagery data before and after the tsunami and photos taken at the time of field survey. The satellite imagery data which were taken by a high performance observation satellite "QuickBird" of Digital Globe, Inc. US on June 23, 2004 and December 28, 2004, were used. The satellite imagery data from these two periods and ground photos taken at the time of the field survey were superposed on GIS. Then, the distribution of buildings before and after tsunami by visual observation wad identified. The washout ratio was obtained from following formula (1) .

$$WR_B = (NB_b - NB_a) / NB_b \qquad (1)$$

WR_B: Washout ratio of building,

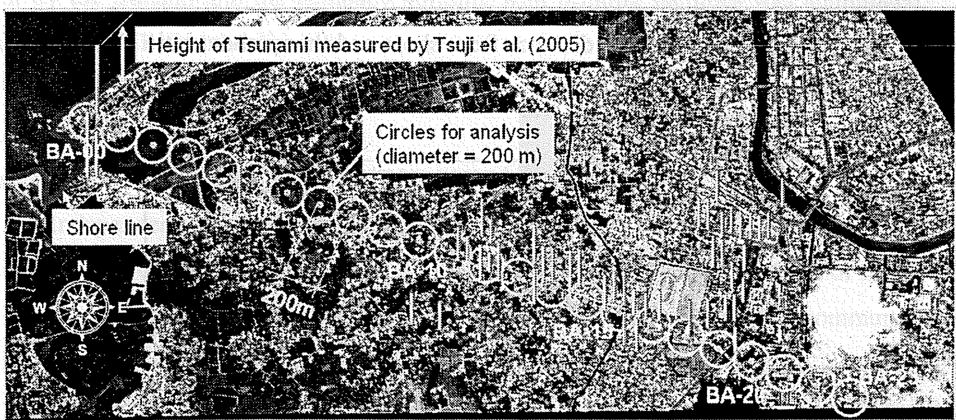
NB_a: Number of buildings that remained after tsunami,

NB_b: Number of buildings before tsunami

Target area for analysis is as shown in Figure 2. An analysis line is set from a survey point BA-00 (Latitude 5.558858, Longitude 95.283574) in a coastal fishery area called Uleelheue, to a survey point BA-23 (Latitude 5.544728, East longitude 95.322599) located at the center of the urban area. Along the analysis line, the number of buildings was counted before and after the tsunami within a circle of a diameter of 200m at survey points that were set every 200m. Then the washout ratio at each survey point was calculated. Figure 3 shows the result. Within about 2km from the shore, almost 100% of buildings were washed away, and the new urban district that has developed between the coast fishery area and the center of the urban area suffered serious damages. In the area from 2 to 3.5km from the shore, many buildings were swept away. Areas further than this from the shore suffered almost no damage physically, and were in striking contrast with the seriously damaged area. This contrast was one of the features of damage distribution.

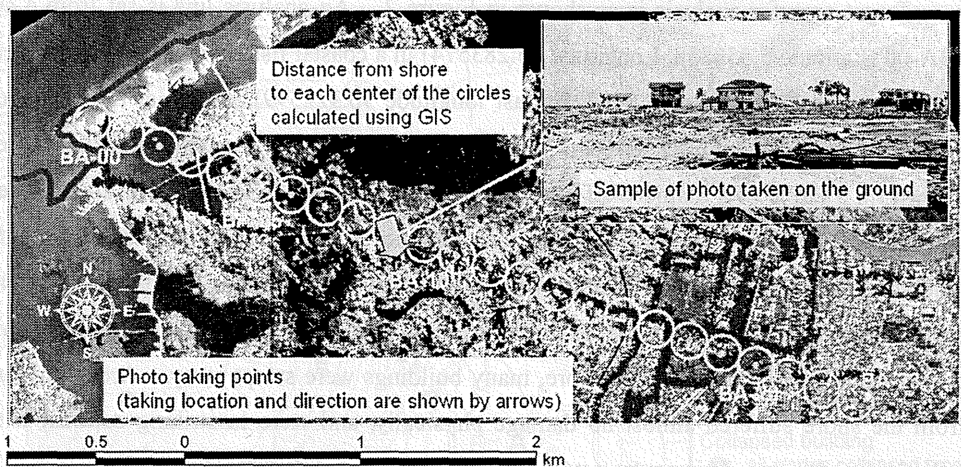
Along the analysis line of this survey, tsunami height measurement was performed by Tsuji *et al.* [4]. In the future, the relationship between the tsunami force and building washout rate will be examined.

Many buildings were swept away, while many mosques maintained their original shapes in spite of the completely devastated situation of surrounding area. Figure 4 shows distribution of the remaining mosques and a sample photo. The reasons why mosques could survive a tsunami were listed as follows. 1) The floor was elevated from the ground and the foundation works were robust. 2) There were few walls and water ran through the mosque smoothly; especially 3) there was no wall attached to the main column, 4) the shape of columns were round, 5) those buildings were constructed carefully, taking about ten years, based on contributions.



a) Satellite Image by QuickBird (before Earthquake and Tsunami: 06/23/04)

[4] Tsuji, Y., *et al.*: Distribution of the Tsunami Heights of the 2004 Sumatra Tsunami in Banda Aceh measured by the Tsunami Survey Team, http://www.eri.u-tokyo.ac.jp/namegaya/sumatera/surveylog/eindex.htm, (2005.3.)



b) Satellite Image by QuickBird (after Earthquake and Tsunami: 12/28/04)

Figure 6.2.2 Study area for building damage due to Tsunami using imagery data

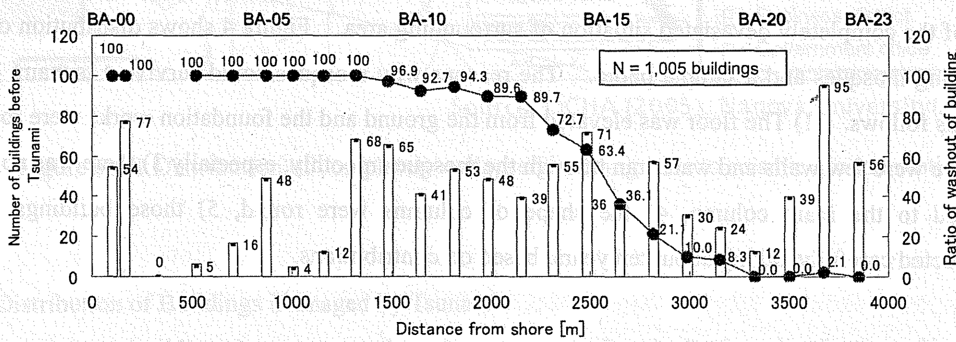


Figure 6.2.3 Relationship between the distance from shore and the washout ratio of buildings due to Tsunami at the analysis line.

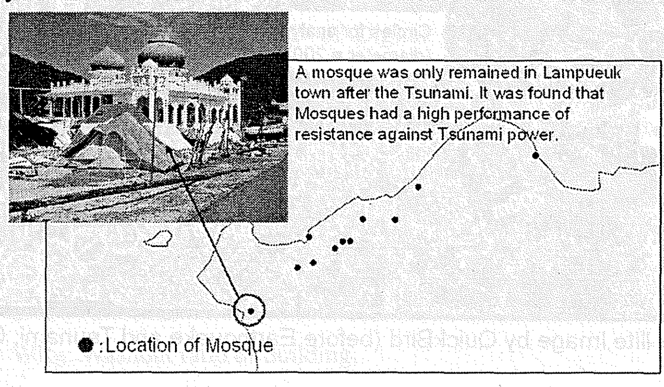


Figure 6.2.4 Distribution of the remaining mosques after the Tsunami attack

6.2.3.2 Physical Infrastructure

Physical infrastructures such as electricity, the communication network, transport links, etc. – which are indispensable for gathering information – were damaged severely by the earthquake and the tsunami. The power network was cut and generators in private compounds stopped functioning after being affected by the flood. Relatively large towns such as Banda Aceh and Meulaboh experienced massive power blackouts. In turn, power blackouts caused the functional failure of the Automatic Telephone Centre, which resulted in service interruption of 50,000 telephone lines in Banda Aceh. Relay aerials for cellular phones were also damaged and this affected the network. As far as transportation was concerned, roads along the coast were cut in pieces by the tsunami, and this made it difficult to grasp the situation in remote areas, especially in the Southwest coast.

6.2.3.3 Social Infrastructure

Government departments, supposedly the base for information gathering and distribution, could not function well during and after the tsunami. Relatively large towns, where district-level government functions were concentrated, were struck severely by the earthquake and tsunami. These included Banda Aceh (capital city of Aceh), Calang (principal town of Aceh Jaya), and Meulaboh (principal town of West Aceh). Many government officials, both at provincial and district levels, were killed by the tsunami, including the mayor of Banda Aceh and his deputy. Surviving government officials had been engaged in taking care of their respective family matters. It was difficult in each government department to list the surviving officials, until all government officials were commanded to report to their offices on 15 February 2005.

The press network was damaged as well. *Serambi Indonesia*, a local newspaper in Aceh, was hit by the tsunami and the company building with printing facilities was annihilated. Many journalists were killed in the disaster.

6.2.4 Activities on the Ground

(1) Group-to-Group Relations

Independent and voluntary activities were undertaken in the disaster area. Communities made up of survivors, whether in government departments or in private companies or in any form of organisation, set up *poskos* (coordination posts) to represent and work for the community without direction from the central government or their supervisory authorities. People from non-affected areas served food to tsunami victims through *posko*. There were also attempts by individuals to offer information on missing persons by placing notices on walls in town and by using the advertisement columns of newspapers.

People living outside Aceh were concerned about the situation in Aceh. Some went so far as to visit the tsunami-affected areas in Aceh to look for their family members, relatives or friends.

Information on the situation in Aceh was at first passed through personal communications, beginning with those who visited Aceh, and soon circulated through cellular phones and Internet.

Foreign governments as well as international organizations expressed their willingness to help the people of Aceh during the disaster, and volunteers and aid workers of various origins arrived in Aceh in droves. The Indonesian government and the state army, which had been prohibiting foreigners from entering Aceh, allowed foreign aid workers and volunteers to operate there, as they were well aware that the rescue operation could not be undertaken by the government and the state army alone. According to a source in the Indonesian government, there had been 380 registered foreign NGOs in Aceh and an additional 163 NGOs had been in action without registering themselves with the government. This showed the generosity of people around the world to the disaster victims. However, it must also be noted that the rush of aid to Aceh somehow took on the character of a competition. Many of the volunteers and aid workers had to undertake their mission in Aceh without sufficient knowledge of the local society. Local press reported troubles between the foreign volunteers and the local communities, which were reported to have originated from misunderstandings on religious implications of their actions.

(2) Circulation of Information

As there had been no official body to gather and provide information systematically, people tried to gather information by themselves, using various means. Among them, Internet turned out to be a useful tool for the purpose. Local newspapers featured the tsunami disaster and set up special sections for tsunami-related articles on their websites. Achenese students studying abroad set up websites immediately after the tsunami to share information on their family, relatives, and friends in Aceh.[5]

Circulation of information through Internet was well received by the volunteers and aid workers. The aid workers were in need of information on Aceh – including maps, demographic statistics, and current situation – in order to implement their activities effectively. The websites of Aceh Media Center[6] and the Humanitarian Information Center for Sumatra[7] were examples. Government agencies in Indonesia provided basic information including maps and statistics to these websites. Similar attempts can be seen on some Japanese websites.[8]

(3) The Role of Mosques

Mosques turned out to have much potential in preventing and reducing tsunami damage.

---

5 http://groups.yahoo.com/group/gempaaceh/

6 http://www.acehmediacenter.or.id/

7 http://www.humanitarianinfo.org/sumatra

8 http://www.drs.dpri.kyoto-u.ac.jp/sumatra/index-e.html; http://homepage2.nifty.com/jams/aceh01.html (in Japanese).

Mosques, as the centre of each village in Islamic society, are located throughout the region. Mosques are places where people gather daily for worshipping and for other purposes. It is a common practice for Muslims to take shelter in their mosque when confronting hardship, especially in Aceh where there have long been armed conflicts. Moreover, mosques in Aceh noticeably survived the earthquake and the tsunami with only minor damage.

Mosques became the base for Islamic organisations both from within and outside of Aceh to help tsunami victims. During the field survey we encountered two groups of Islamic organisations at a mosque in Aceh Besar. One group came from Java and the other from Singapore. Each group consisted of five to seven people and visited as many mosques as possible in the region by using a van. Islamic organisations gave relief aid as well as religious services through mosques, and such religious services were able to help people to confront post-disaster impacts.

There is also the potential for mosques to become the basis for a tsunami warning system. Information or early warning of tsunamis can be given to villagers by using the speaker which every mosque is equipped with in order to broadcast the timing of worship to local Muslims. During the field survey, we experienced aftershocks in Banda Aceh. People panicked as they were afraid of another tsunami, and became calm after announcements were made through the speakers of mosques, saying that there was no possibility of a tsunami.

6.2.5 Damage to Cultural Assets

(1) Library of Ar-Raniry State Institute of Islamic Studies

Ar-Raniry State Institute of Islamic Studies (Institute Agama Islam Negeri Ar-Raniry) took its name from a famous Muslim *Ulama* (religious leader) and is located in the northeast of Banda Aceh. There seemed to be no serious physical damage to the three-story building of the library after the earthquake and the tsunami, except for a crack along the joint part of the two adjoining buildings of the library, which was caused by the earthquake.

The ground floor of the library was affected badly by the tsunami. Of the total of 288,600 books stored in the library, some 7,000 were damaged. Those books were newly accepted to the library and were temporarily put in rooms on the ground floor for classifying procedures. According to a library staff member, about a half of the damaged books seemed likely to be reusable after the necessary processing, though the library had no appropriate equipment.

(2) Library of Syiah Kuala University

Syiah Kuala University (Universitas Syiah Kuala) is located next to the ar-Raniry State Institute of Islamic Studies, but the university sustained little damage from the tsunami as the partition line between affected and non-affected areas ran between the university and the institute.

The university had a library with an independent three-story building. Damage to the building was mainly caused by the earthquake. Floor tiles were cracked, bookshelves fell, and a part of the ceiling dropped to the floor. However, there was no damage to the collection of books due to the earthquake.

(3) Aceh Regional Branch of the National Archive

Aceh Regional Branch of the National Archive (Perwakilan Wilayah Aceh Arsip Nasional) is located in the northeast of Banda Aceh. The ground floor of its two-story building was flooded and severely damaged by the tsunami. A motorcycle and a car were washed onto the ground floor with a large amount of mud, through the broken windows of the building.

There was a workroom on the ground floor of the archive. Before the tsunami hit, copies of official documents printed by each department of the provincial government in Aceh were collected and temporarily put in the room, before either being stored permanently in the upper floors or being disposed of according to their importance. A small number of documents were on display on the ground floor. The tsunami flooded the workroom with muddy water and the documents in the room were damaged irreparably.

Important documents were kept in the locked rooms on upper floors and there was no direct damage to these documents by the tsunami. However, it might be a problem that the surviving documents on the upper floors have been left in the same condition, without air-conditioning or other equipment, since the tsunami.

Apart from the physical damage to the building and the documents, the archive suffered the deaths of 11 staff members.

(4) The State Library of Nanggroe Aceh Darussalam

The State Library of Nanggroe Aceh Darussalam (Perpustakaan Wilayah Nanggroe Aceh Darussalam) is located in the government office quarter, one of the tsunami-affected areas in Banda Aceh. The ground floor of its two-story building was piled up with mud, and literally everything on the floor, including furniture, was disposed of as rubble. Seventeen people were employed for the clearance of the rubble and mud, and it took some weeks to clear up the ground floor.

There were about 200,000 titles in the library. Ninety percent of the books put on the first floor were damaged by the flood, of which two percent were newly arrived. Books on the ground floor were mainly either reference books or books for children.

Some 12,000 titles in the Aceh collection were placed in a room on the second floor and were not damaged by the tsunami. The collection contained academic exercises by Syiah Kuala University students, and back issues of *Serambi Indonesia*, a local newspaper in Aceh. Part-time workers as well as volunteers helped the library to remove mud and re-arrange books, though the library was upset by some volunteers who had taken the library books as souvenirs.

There was also a loss of staff, including the director who was killed by the tsunami.

(5) Aceh Documentation and Information Center

Aceh Documentation and Information Center (Pusat Dokumentasi dan Informasi Aceh) was located in front of Blan Padang Square near Grand Mosque. Its one-story building collapsed to the ground and there was almost nothing but the foundation stones, as rubble had been removed.

Before the tsunami came, the centre stored books and documents related to Aceh's history, mostly Indonesian translations of Dutch official documents, translated and printed by the centre in 1970s. It seemed that almost all the books and documents in the centre were totally lost, except for a few copies of books scattered around the site.

(6) Library of Ali Hasjmy Foundation for Education

Ali Hasjmy Foundation for Education (Yayasan Pendidikan Ali Hasjmy) is located in the area in Banda Aceh where the tsunami caused little damage. At the time of our field survey, many houses in the area were rented to international/foreign organizations and became their headquarters.

This library was founded privately by Ali Hasjmy, the first Governor of Aceh. The library has some 1,500 titles including books and documents written in Acehnese, Indonesian, English and Dutch. The collection of the library also includes documents compiled by Ali Hasjmy, copies of old and rare versions of the Quran collected by Ali Hasjmy, old manuscripts and photo albums.

The tsunami reached less than one foot high in the building and had little effect on the building. However, local press reported that some books in the library were soaked with water because the books had dropped from the bookshelves to the floor during the earthquake.

(7) Syiah Kuala Grave

Syiah Kuala Grave (Mahkam Syiah Kuala) is located at the north tip of Banda Aceh, about 50 meters from the coastline. Syiah Kuala was one of Aceh's great Muslim *Ulama* of the 16th century. He had spent more than 15 years in Mecca for religious learning before he dedicated most of his life to science and society. He wrote many books on Islam, social studies, and science. He also had a lot of students from Malaysia, West Sumatra and Java.

In Syiah Kuala Grave, Syiah Kuala and his 48 students lay under their tombstones. The grave had been taken care of very well by the local community. Places for rest and worship were prepared around the grave, and people often visited the grave for these purposes. When the tsunami came, nearly everything in the grave was washed away. In the neighbouring village, only 300 villagers out of 2,000 survived. However, the tombstone of Syiah Kuala remained almost unaffected by the tsunami; only the surrounding steel fences were bent by waves. It is now known as the tombstone that withstood the tsunami, and many people are attracted to the supernatural powers of the grave.

(8) Aceh Museum

Aceh Museum (Museum Negeri Banda Aceh) is located near the Governor's residence. The main building of the museum is a house built in traditional style by the Dutch Governor Van Swart in 1914. The museum is filled with antiques, and among the exhibits is a big bell, Cakra Donya – a gift from the Emperor of China conveyed by Admiral Cheng Ho in 1414.

The museum was not affected by the tsunami, though local press reported that some exhibits had fallen to the floor and been damaged due to the earthquake.

(9) Land Certificates

Land certificates kept in the National Land Agency (Badan Pertahanan Nasional) were also damaged by the tsunami. According to the government announcement, about three to five percent of the land certificates kept in Banda Aceh were damaged by the tsunami. The government put forward the view that land ownership in Banda Aceh could be restored by using maps and satellite photographs.

Another source revealed that thousands of land certificates affected by the tsunami in Banda Aceh were in critical condition and in need of emergency treatment. Efforts to preserve and restore the certificates were undertaken with the support of Japanese experts.

(10) Judicial Records

The State Court (Pengadilan Negeri) of Aceh is located next to the Aceh police headquarters in Banda Aceh. The court was affected by the tsunami and a great number of judicial records were damaged. The government announced its stance that the court should re-conduct the trials if the related records were lost.

6.2.6 Remarks

The December 2004 Sumatra earthquake and tsunami caused extremely serious harm to the society of Aceh. Apart from the magnitude of the damage, the relatively slow development of physical and social infrastructures in the region before the tsunami caused difficulties in gathering information on damages during the crisis.

Under such conditions, people eagerly gathered and circulated information. In the process of restructuring the society, the use of Internet and mosques turned out to be effective. The remaining issue is networking between the aid workers/volunteers and such websites.

Acknowledgements

We thank Prof. Thanthawi of Syiah Kuala University, our research counterpart, and Mr. Sanusi Wahab for their hospitality, cooperation and information. Without their assistance, our field research would have been very difficult. We also owe debt to many community members and government and non-government staffs for their generosity of providing us with valuable time and information.

6.3 Socio-cultural Impacts and Responses in Southeast India

6.3.1 Introduction

Field research was conducted from February 20th to March 5th, 2005. The purposes of the research are as follow;

(i) To know the details of relief and rehabilitation works and the behavior of the affected people after the tsunami disaster.

(ii) To understand whether local people had knowledge of tsunami beforehand, and how the information of tsunami spread among the people just after the incident.

(iii) Y. Sugimoto also focused on the role of religious organizations on the relief and rehabilitation works.

(iv) S. Sugimoto also aimed at knowing how the fishermen society and their network worked for the relief and rehabilitation of fishing villages.

(v) As an archaeologist, Fukao's personal research interest is the extent of the damage on tsunami affected cultural monuments located on the east coast of Tamilnadu.

6.3.2 Outline of Damages

In the morning of Dec. 26th, 2004, the tsunami traveling across the Bay of Bengal arrived at the coast line of South India, and brought down massive damages to the people, infrastructure and utilities located on the coastal areas in Tamil Nadu, Kerala, Andhra Pradesh, Pondicherry and Orissa in Indian subcontinent (see Figure 6.3.1). Among them, Tamilnadu is the most severely affected state. The total number of the death caused by this tsunami in India, including Andaman & Nicobar Islands, amounts to more than 10,000 (see Figure 6.3.1).

(1) The worst affected area in Tamilnadu is Nagapattinam District (for the details of the death, see Fig. 2), which is known for its religious harmony with a well-known church of Velankanni and mosque of Nagore. Nagapattinam is a chief port town to anchor large trawling vessels, and ships and fishermen's settlements were badly damaged there (Photo 6.3.1).

In Velankanni, there was a good crowd in the famous Christian basilica (Photo 6.3.2) on the day, being the next day to the Christmas Day. Most of the pilgrims and tourists assembled at the beach side were carried away by the tsunami.

(2) Cuddalore District, near Pondicherry, known for fishing harbor and fishing settlements on the numerous sandbars, is another area extensively affected by tsunami (see Fig. 3.) Devanampattinam and Pudukuppam of Cuddalore coast were the centre of the attack.

(3) Kanyakumari, the southernmost town of Tamilnadu, is one of the famous tourist spots in India. The district of the same name was the second worst affected area in Tamilnadu (see Fig. 4), and fishing villages, like Colachel, Kottilpadu, Melamanakudi, etc., located west of Kanyakumari

town, were badly damaged. The real picture of the attack of the tsunami is recorded in video CD we obtained there.

(4) In the city of Chennai, Marina beach, city dwellers' favorite place, got inundated, and a large number of people including children gathering for the morning walk and play were affected. Fishing hamlets in Kasimedu and Srinivasapuram, north and south of Chennai respectively, incurred a heavy loss in terms of life and properties. Besant Nagar, a new residential colony in the southern side of Chennai, was also badly damaged.

We should note that we cannot definitely say that the statistical data shown in the tables here really represent the exact status of the damage because there are still a number of missing persons taken by the tsunami some of whom may have not been included in the record, also because we do not know if the damages in some inaccessible areas, like Andaman & Nicobar Islands, etc., were exactly reported.

6.3.3 Overview of the Relief and Rehabilitation Works

From the words of the witnesses of the disaster, the magnitude of the damages caused by the tsunami is vividly known to us.

After the attack of the tsunami on Dec. 26th, the main lifeline of the town, like foods, water, electricity, and telephone connections, were discontinued immediately. Though in some part of the town, power supply was recovered on the next day, in many areas non-availability of water, power and telephone connections continued in three to seven days.

In Nagapattinam, many of the residents in the damaged areas left for inland towns nearby, like Thiruvarur, Thiruthuraipoondi, etc. for shelters. Public facilities in the town, like schools, community halls, etc. were also used for temporary shelters. Local people generously helped the affected people. For example, in Thiruvarur, local people gave shelters to the displaced people from Nagapattinam area in nearly one week. Dargahs (mausoleums of Islam saints) in Nagore and Christian churches in Nagapattinam and Velankanni helped people irrespective of regions and castes. Their activities in some sense contribute to weakening religious tensions in the area.

Local NGOs started the emergency relief works earlier than governmental bodies to supply basic needs for the displaced people, like foods, water, and medicines, etc. Recovery of dead bodies was a very difficult task, and continued in more than a few days. Many unidentified bodies were buried collectively after taking photos for the future identification. Many volunteers worked for the collection of dead bodies.

Under such circumstances, the relief and rehabilitation works were operated in the affected areas.

6.3.3.1 Relief Works of Christian and Communist Related Organizations

Christian and communist related organizations, like TMSSS, DMI, CPI (M), Tamilnadu Science Forum, etc. played a very important role on the relief and rehabilitation works in the area.

We do not intend to say that only those organizations were actively engaged in relief and rehabilitation activities. However as far as our research areas are concerned, Christian and communist related organizations occupies very important position in daily life of the people in the area, and of course, in relief and rehabilitation works on this occasion.

(1) Quick Response for Initial Relief Activities

Christian and communist organizations started the initial relief operations at the very early stage after the disaster.

TMSSS, Christian voluntary organization stationed in Velankanni Basilica, responded to this sudden disaster very quickly. Father Adaikkalaraj told us that they had arrived at the affected area in about two hours after hearing the news of the tsunami in the television. At 4:00 p.m. on the day, the meeting to discuss the relief measures was held by the bishop and parish priests of the area, and decided to send 400 volunteers to recover the corpses, and supply the foods to the displaced people.

In Cuddalore, the member of Tamilnadu Science Forum, communist oriented NGO, visited the worst affected village, Devanamppattinam at 9:45 a.m. after receiving the first information over the phone at 8:45 a.m.

Sisters of Presentation Convent, Colachel, Kanyakumari Dt., heard the news of the tsunami around 10:20 a.m. when they had a breakfast after Sunday mass, and rushed to the Nagle Health Center maintained by them for helping the injured.

In Kanyakumari Dt., Communist Party of India (Marxist) also moved very quickly. Receiving the information over the phone within 30 minutes after the attack of the tsunami, the District Secretary and two other chief members of Nagercoil CPI (M) office visited the worst affected areas at around 11:20 a.m. At 12:30, they had a meeting with the District Collector along with church representatives to discuss about the relief measures. At 3:00 p.m. on the day, a central committee member was sent by state party office in Chennai to see the situation of the sites.

(2) Extensive National/International Network

Utilizing their national/international networks, Christian and communist organizations could smoothly gather the human power and the materials to conduct the relief measures.

Christian youth volunteers from the inland parishes near the affected areas, and from other districts, like Thanjavur, Madurai, Trichy, etc., gathered their power to recover dead bodies, and support the displaced people. From Chennai, nearly 200 DMI sisters, brothers, and novices took 7 school vans to go to the affected villages in Kanyakumari area to supply foods, clothes, and medicines on the day of the disaster itself.

Communist party has also extensive network all around the country. Kunyakumari District office in Nagercoil, where communist party has a strong existence, contacted with State CPI(M) office in Chennai, and Centrail office in Delhi on the day of the disaster itself to discuss about the relief measures. Youth organization affiliated to communist party, like DYFI (Democratic Youth Federation of India), and SFI (Student Federation of India), effectively worked to gather human power. Relief materials arrived from Kerala and West Bengal too, where communist party is a leading political party.

Those organizations utilize their international network to gather the relief funds and materials too, like in the case of International network of Presentation Sisters of the Blessed Virgin Mary (PBVM).

(3) Deep Relationship with Affected Communities & Coordination with Other Organizations

One of the reasons why Christian and communist organizations could effectively work for the relief and rehabilitation against the disaster this time is that they have already had a close relationship with the local people in these areas through their daily activities.

We heard at CPI (M) Nagapattinam office that they could distribute the relief materials to each affected family because they have been already familiar with them, and they could give the goods to the people face to face.

Especially in Kanyakumari Dt. since the affected fishermen community is Roman Catholic in general, Christian organizations are closely related with their daily life. People in this area are organized as Basic Christian Communities (BCC) which is a local autonomous group of lay Christians, and local parish priests have a deep connection with local people through BCC. BCC is an organization originated from the idea of the Theology of Liberation. Local people conveyed their requests regarding tsunami relief easily to local parish priests through BCC. High literacy rates and consciousness on their own right also contribute to the smooth flow of information between local people and higher authorities.

Most of schools maintained by churches were used for supplying relief materials and for sheltering the affected people. Loud speakers set up at churches were also effectively used to deliver the information related with relief works, etc. Mostly local people believe church authorities that they distribute the relief goods fairly and impartially.

Bishop of Kottar Diocese who supervises this area also took an important role on relief activities. He sailed around the affected coastal regions on a boat in order to cheer up the discouraged fishermen. He also took effort to contact with other relief organizations in order to coordinate their works.

Through this close relationship with local people, they also actively worked as a coordinator to connect other relief organizations and governmental bodies.

We were told in Cuddalore that communist affiliated Tamilnadu Science Forum was actively involved with Tsunami Rehabilitation Coordination which is a NGO to work for the adjustment of the activities of various NGOs. It is interesting to note that in Kanyakumari Dt., CPI(M) district office and the Bishop of Kottar Diocese jointly met the Collector and Health Minister to discuss about the coordination of the relief and rehabilitation works, and CPI(M) also talked with local parish priests to coordinate the actual work for supplying the relief materials.

6.3.3.2. Preconception of 'Poor' Fishing Communities

It is said that nearly 90% of the affected people in India are fishermen. There is a general conception that fishermen communities are poor and uneducated, and most of the relief and rehabilitation works are conducted according to this concept. It is true that in respect of higher population density, lower literacy rates, and uneven sex ratio in their population, fishing villages in Tamilnadu as a whole show a sort of marginality comparing with other communities. (see Fig. 5) However it does not necessarily mean that the entire fishing communities in tsunami affected areas are socially weak and deprived.

(1) Fishery communities mostly consist of various castes of people. In fact, for example, fishing community in Nagapattinam area is not represented by a single community, but it includes various kinds of people, like Kallar, Chettiyar, etc.

(2) It is not correct to say that all the fishermen in the affected area are poor. In Akkaraipettai, Nagapattinam District, 80% of the fishermen possess their own ship, and many of them conduct a large scale fishery by a large trawling vessel far off shore. In high season they can sometimes earn even ten Rupees of money only in a three days' fishing work off shore if they are very lucky. Women can also earn sizable money by selling fish in the market, and paddling.

(3) The social stratification in the people engaging in fishery is also evident from the research. As said before, some of the fishermen are very rich, on the other hand, people belonging to Dalit, the outcaste community, engage in a hard manual work related with fishing, and they are in fact poor and socially neglected.

(4) In addition to that, we should also note that the affected communities by this disaster are not only the people directly related with fishing activities, but also other communities are also directly/indirectly affected. Agricultural communities suffered a lot of loss in their fields' harvesting rice, and other commercial crops like tobacco, jasmine, mango, cashew nuts, etc. A large decrease of the supply of fishes and harmful rumor that fishes are poisonous because they eat human corpses damaged the people engaging in commercial activities. Decrease of tourists in some tourist spots like Velankanni, and Mamallapuram, etc. affected tourist industries.

This gap of the notion and reality hindered the effective relief and rehabilitation activities.

(1) The relief materials mostly concentrate on the fishermen. Other affected communities could not get sufficient relief. (2) The effective distribution of the relief materials was hindered. For example, old clothes supplied for the tsunami affected people were discarded and heaped unused because they usually dislike old clothes. Relief foods were brought to the market from the hands of the affected people in order to earn cash. At the time of supplying relief goods, rich fishermen do not like to stand in the same queue with poor communities.

6.3.4 Information about Tsunami and the Revival of Mythology

Local people affected by the tsunami here in Tamilnadu did not have any fore knowledge about what is tsunami. This is clear from the fact that many people went down the shore when the water receded before the attack of the tsunami, and were brought away to the sea.

If the information about the arrival of tsunami had been properly conveyed to the people in the affected area, there would have been much less damages than really happened. The effective way of information transmission can be considered from the experience of an important role took by a radio station and PAS.

Tsunami brought not only huge damages in this region, but also is contributing to creating/reviving some new legends in some sense.

6.3.4.1 Role of Radio Broadcasting and PAS

(1) Example of All India Radio Karaikkal Station

All India Radio Karaikkal FM Station is located about 1.5km from the sea shore. Around 9:00 a.m. people living in the staff quarters adjacent to the station noticed the coming of the tsunami, and the information directly went to the station. At 9:48 the first announcement was made breaking the film song program. Program officers immediately went to the field on the seaside, and made live broadcasts by using cell phones. At 10:45 Kodaikkanal station relayed the program of Karaikkal station and the program was broadcasted to the wider audience in the state.

Live broadcast from the damaged places was able to give the correct picture of the damages. Information about the destroyed bridge and the safety roads helped the smooth transportation to and from the town. The station continued the broadcast overnight up to 10 p.m. on the next day though it usually finishes at 10 p.m. on the same day.

From the next day onward, there were many programs related to the tsunami, like the information of the missing persons, the information from governmental organizations, the arrangement of relief materials, the knowledge to maintain hygienics, needs for people in relief camps, etc.

A week after, there was a scientific program with a geologist about the mechanism of tsunami which was carried out as a live transmission of question and answer over phone from the public.

Karaikkal radio station contributed to conveying the information from the public to governmental & non-governmental organizations and vice versa.

(2) Importance of Public Address System

Near Pondicherry, lives of the residents of two villages were saved owing to public address system (PAS).

At Nallavadu village, a resident of this village living in Singapore heard about the tsunami warning, and phoned up the village. The village elders asked the villagers to vacate houses by PAS, and the entire population of 3,600 people survived from the tsunami.

At Veerampattinam, a fisherman repairing the engine of his boat on the beach noticed the unusual rise of the sea level, and warned the women working there. The warning reached the panchayat leaders, and they announced over the PAS about the attack of the waves. There only one person died among the 6,200 villagers.

PAS was set up by M.S. Swaminathan Research Foundation, Chennai, as an equipment for rural knowledge centers.

6.3.4.2 Reinterpretation of Traditions

(1) Poompuhar

Ancient Tamil epic 'Silappadikaram' depicted this presently small town as a beautiful, big city which flourished by the international trade with Roman world under the reign of Chola kingdom in early Christian centuries. Archaeological finds, like Roman & Greek coins, semiprecious stone beads for export, the remnants of a boat jetty, etc. also attest the past glory of this town. It is said in the literature that Poompuhar 'was taken by the sea.' After the present tsunami, people now say that it might have been another tsunami that vanished the once busy city of Poompuhar from the history.

(2) Mamallapuram

Mamallapuram, also called as Mahabalipuram, is situated about 50km from Chennai. This is a famous tourist place in Tamilnadu known for the famous Shore Temple, the World Heritage monument built in 7th century (Photo 6.3.3). There is a beautiful rock relief of 7th century called 'Descent of the Ganga' (or 'Arjuna's Penance') (Photo 6.3.4). Usually it is said that it depicts the mythological scene of Goddess Ganga's falling down on the earth accepting the prayer of king Bhagirata who did a penance for this purpose. Now some people say it depicts the attack of tsunami.

There is another legend here in Mamallapuram that the famous Shore Temple was one of the 'seven Pagodas' built in the same period. Recently revealed new temple structure, as explained below, and some kind of structure found by underwater research off shore rekindle this legend.

Some people even said that they saw some temple structure when sea water receded before the tsunami.

(3) Velankanni

The Church of Our Lady of Health situated in Velankanni gathers a number of Christian, even Hindu, pilgrims and tourists from all around India. The legend related to this basilica says that Mother Mary and Infant Jesus saved the wrecked Portuguese ship. This time's tsunami left immense damages in this area too. People who experienced this disaster in Velankanni interpret it in two different ways; (a) For the people who have a firm belief on the church, the fact that the water could not enter into the church building at all means that the God saved them this time again like the Portuguese fishermen. (b) On the other hand, people who cast a doubt on their belief consider that the God could not stop happening this tragic incident. A new legend may be created from somewhere between those two opposite views.

6.3.5 Cultural Properties and Tsunami

There are some places of archaeological importance on the east coast of Tamilnadu. Fukao did some preliminary survey regarding the effect of the tsunami on those important cultural monuments.

(1) Tarangabadi

Tarangambadi, also called Tranquebar, is situated at about 25km north of Nagapattinam. There is a well-known 'Dansborg Fort' built as a trading post for Danish government in 1620 (Photo 6.3.5). Although the waves reached the main road and heavily damaged the fishing settlement nearby, the fort was not affected at all by the waves attacking upon the door of the fort which is situated just 100 meters from the seashore.

Besides the fort, the stone memorial commemorating the second centenary of the arrival of the first Lutheran missionaries to India in 1706 was not much affected but the surrounding stones were disturbed by the tsunami.

14th century Masilamaninathar Temple (built by Maravarma Kulasekara Pandiyan in 1305) just north of the fort had been already much destroyed by seasonal cyclones, but not damaged by this tsunami less than estimated (Photo 6.3.6).

The bastion of the fort standing off shore was also not much affected though it was disturbed by the seasonal cyclones.

(2) Arikamedu

Arikamedu, a famous archaeological site, is located 4km south of Pondicherry, on the right bank of the Ariyankuppam River. It was an important port town flourishing through the trade with

Rome in the first two centuries of Christian era.

Virampattinam, a fishing village adjacent to Arikamedu, was devastated by the tsunami though only one person was dead as already written. From the site, there were seen in the river some fishing vessels brought from the village by the waves.

The tsunami water is said to have entered up to about 1.5km from the sea shore here. However since the site itself does not directly face to the sea, and is situated on the high mound, it seems that the site was not affected much.

We do not know how much a lower portion of the site was affected. A further research will be required.

(3) Mamallapuram

The Shore Temple, the World Heritage monuments built by Pallava king Narasimhavarman II (ca. 690-715) is located just in front of the sea shore here (Photo 6.3.3). December 26th's tsunami destroyed a portion of a block wall and a fence protecting the temple, and flooded into the premises. Though a few boulders of the outer wall of the temple and a part of bali peetha were dislocated by the invaded water, the main structure of the temple did not get much damage.

While the newly prepared lawn garden and several shops near the temple were also submerged, the tsunami contributes to revealing some new monuments on the sea shore.

One of them is so-called 'Durga Rock' situated south of the Shore Temple. A miniature cut-in shrine carved on this rock which was probably built in the almost same period as the Shore Temple was already known before the tsunami, and is worshipped by fishermen. The tsunami waves washed away the sand hiding the lower portion of the rock, and revealed the sculptures of lions, an elephant, a horse, warriors, etc. (Photo 6.3.7)

Underwater Archaeology Division of Archaeological Survey of India has conducted excavation works here since 2001. 'Durga Rock' was one of the targets to be excavated this year according to the original plan made before the tsunami, along with other two rocks having cuttings presumed to be chiseled out in the same period as other monuments on the shore. However after the tsunami a new structure was clearly seen between 'Durga Rock' and the 'Shore Temple', and the excavation team selected it instead of 'Druga Rock.' The excavation started from Feb. 17th revealed the square structure of sanctum sanctorum, a shikara stone, and a part of the outer wall, etc. that is remains of an old temple structure though its exact date was not known yet.

6.3.6. Conclusion

(1) Locally active organizations which have a national/international scale of well-organized systematic structure play a very important role on relief and rehabilitation works

against sudden large scale disasters like the tsunami this time, like Christian organizations and communist related organizations in the case of the researched areas. It is not so difficult task for them to absorb the opinion and feelings of local people because they regularly contact with them through their daily activities, and their systematic organization helps them to conduct a national/international scale of relief and rehabilitation activities.

(2) Stereotyped notion that poor fishermen were affected by the tsunami hampers the effective relief and rehabilitation works.

(3) In India, radio broadcast can play a very important role to quickly respond to this kind of sudden large scale disaster for conveying an exact picture of the damage. PAS is also proved to be a very useful equipment for urgent warning of this kind of disaster.

Fig. 1 Tsunami Affected Area In India

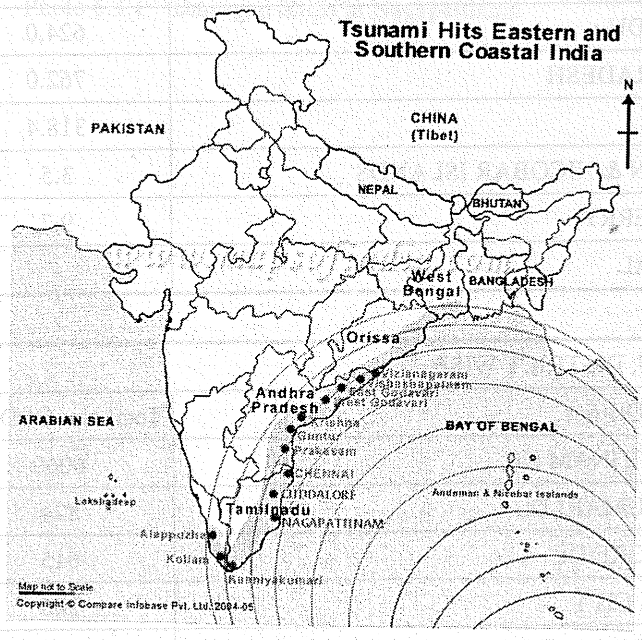


Figure 6.3.1 Tsunami Affected Area in India

(4) It seems that most of the cultural monuments located on the eastern coast of Tamilnadu escaped the damage by the tsunami. Further researches will be required to know the whole picture of the damage and the reason why many monuments escaped the damage.

It is observed that the reports of the tsunami made by Japanese and western mass media did not put equal weight on all the affected countries. Thailand where many foreign tourists were affected in resort towns was most frequently reported, as well as Sri Lanka where also Japanese tourists met the incident. Indonesia, the most damaged country, comes to the second position only after the information from Ache region was brought in. It clearly shows that India did not draw much attention of the mass media of the developed countries comparing with the degree of damages cause by the disaster. One of its reasons may be the fact that Indian government rejected the aid from those developed countries although the reason why Indian government took such a position should be studied separately. On the other hand, it can be also said that this imbalanced flow of information reflects uneven structure of this world. This kind of large sudden disaster will create unexpected chaotic situation something like anthropologically called 'liminality', and it will often reveal usually hidden unequal structure of society, country, and the world.

Table 6.3.1 Death caused by Indian Ocean Tsunami on Dec. 26th, 2004

STATEWISE (AS OF JAN. 18Th, '05)		
Name of the State	Population (Lakh)	Total No. Of Death
TAMILNADU	624.0	7983
ANDRA PRADESH	762.0	105
KERALA	318.4	171
ANDAMAN & NICOBAR ISLANDS	3.5	1899
PONDICHERRY	9.7	591
INDIA TOTAL	-	10749

TAMILNADU, DISTRICT WISE	
Name of the District	Total No. Of Death
NAGAPATTINAM Dt.	6060
KANYAKUMARI Dt.	824
CUDDALORE Dt.	615
CHENNAI CITY	206
KANCHIPURAM Dt.	128
TOTAL	7833

Photo 6.3.1 Damaged Ships in Nagapattinam

Table 6.3.2 Death in Nagaoattinam Dt. As Of Jan. 29, 2005

SL. No.	Village Name & Taluk Name	Total Nos. Of Bodies				
		Adult		Children		TOTAL
		Male	Female	Male	Female	
Nagapattinam Taluk						
	Nagore Village					
1	Pattinacherry	30	97	21	17	165
2	Palpannaicherry	6	34	8	4	52
3	Samanthappettai	14	33	8	14	69
4	Silladi Theru	17	34	12	13	76
5	Pandagasalai Street	14	26	10	4	54
6	Beerodum Street	3	9	3	3	18
7	Ariyanattu Street	8	11	4	7	30
	Vadakupoigainallur Village					
8	Vadakku Poigainallur	7	12	12	8	39
9	Akkaraipettai	377	286	64	54	781
10	Keechankuppam	229	479	106	92	906
10	Theederkuppam	32	126	12	10	180
11	Kallar	50	40	18	15	123
	Nagapattinam Village					
12	Nambiyarnagar	43	23	14	12	92
13	Velipalayam Beach	39	31	7	3	80
14	Velipalayam	9	8	14	17	48
15	Ariyanattu Street	163	165	43	32	403
16	Nalliyanthoppu	62	40	30	19	151
17	Therku Poigainallur	39	41	18	11	109
18	Gooks Road	1	0	0	1	2
		1143	1495	404	336	3378
Keevelur Taluk						
1	Velankanni	216	188	96	114	614
2	Prathamaramapuram	1	0	0	0	1
3	Seruthur	243	191	124	114	672
4	Kameswaram	22	22	11	6	61
5	Keezhapidagai	2	2	1	1	6
6	Karaunkanni	1	0	0	0	1
7	Chinnathubur	6	4	0	0	10
8	Pudupalli (Vettaikaraniruppu)	19	17	9	10	55
9	Vairavankadu	27	24	12	15	78
		537	448	253	260	1498
Vedaraniyam Taluk						
1	Pudupalli	0	0	0	0	0
2	Vettaikkaraniruppu	0	0	0	0	0
3	Vanavanmadevi	0	0	0	0	0
4	Vellapallam	19	8	9	8	44

5	Naluvedapathy	3	3	0	1	7
6	Kovilpathu	11	4	3	6	24
7	Pushpavanam	9	4	5	1	19
8	Pariyakuthagai	2	2	3	0	7
9	Arkattuthurai	8	2	5	0	15
10	Kollitheevu	0	0	0	0	0
11	Maniyantheevu	0	0	0	0	0
12	Mottandithoppu	0	0	0	0	0
13	Agasthiyampalli	6	2	0	0	8
14	Kodiyakkadu	0	0	0	0	0
15	Kodiyakkarai	4	4	0	2	10
16	G.H. Vedaraniyam	5	5	1	3	14
		67	34	26	21	148
Tarangambadi Taluk						
1	Chandrapadi	4	42	9	22	77
2	Chinnoorpettai	1	3	2	5	11
3	Sathangudi	37	121	56	70	284
4	Kuttiyandiyur	6	0	2	2	10
5	Puduppettai	5	16	0	11	32
6	Perumalpettai	2	8	8	6	24
7	Kuttiyandiyur	7	6	0	2	15
8	Vellakoil	1	4	10	4	19
9	Talampettai	4	11	3	0	18
10	Chinnangudi	3	12	3	11	29
11	Chinnanmedu	1	2	0	1	4
12	Keelaperumpallam	0	0	0	1	1
13	Erukkattancheeri	0	0	0	1	1
		71	225	93	136	525
Sirkali Taluk						
1	Thirumulaivasal (Thodduvai)	21	45	17	14	97
2	Puduppattinam	5	19	18	12	54
3	Thandavankulam (Madavakudi)	4	7	8	11	30
4	Thennampattinam	8	37	16	29	90
5	Thirunagari	0	1	0	0	1
6	76/1 Perunthottam	3	4	5	3	15
7	76/2 Perunthottam	4	13	3	1	21
8	Keezhaiyur	15	61	36	53	165
9	Vanagiri	5	14	8	9	36
10	Keelamoovarkkarai	0	3	0	4	7
		65	204	111	136	516
	TOTAL	1883	2406	887	889	6065

Table 6.3.3 Death in Cuddalore Dt.

SL. No.	Village Name & Taluk Name	Total Nos. Of Bodies				
		Adult		Children		TOTAL
		Male	Famale	Male	Female	
Cuddalore Taluk						
1	Devanamppattinam	21	42	23	14	100
2	Thazhanguda	6	14	5	10	35
3	Sonankuppam	3	19	8	13	43
4	Singarathoppu	1	15	0	4	20
5	Chithiraipettai	0	0	0	3	3
6	Rasapettai	0	0	0	2	2
7	Suba Uppalavadi	0	1	0	2	3
8	Pachayankuppam	0	4	0	0	4
9	Sothikuppam	1	3	12	6	22
10	Sonagan Chavadi	0	1	0	0	1
10	Akkarai Gori	4	9	1	0	14
		36	108	49	54	247
Chidambaram Taluk						
1	Samiyarpettai	2	19	2	1	24
2	Mudasal Odai	1	5	2	2	10
3	Muzhukkuthurai	2	4	1	1	8
4	MGR Thittu	15	19	14	6	54
5	MGR Nagar Irular Habitation	0	2	1	1	4
6	Chinnavoikkal	1	5	2	5	13
7	Pillumedu	2	5	11	9	27
8	Killai North	0	2	1	2	5
9	Parangipettai	13	21	2	3	39
10	Chinnoor	10	17	1	2	30
11	Pudupettai	8	26	5	4	43
12	Velangirayanapettai	2	3	0	0	5
13	Chinnadikuzhi	0	2	0	0	2
14	Pudukuppam	15	43	19	19	96
15	Thandavarayan Sholaganaapettai	2	1	0	2	5
16	Kumarapettai	0	3	1	0	4
17	C.Manampadi	1	0	0	0	1
		74	177	62	57	370
	TOTAL	110	285	111	111	617

Table 6.3.4 Death & Unidentified in Kanyakumari Dt

SL. No.	Name of the Village	Total Number Of Death				
		Adult		Children		TOTAL
		Male	Famale	Male	Female	
1	Keelamanakudi	10	16	4	5	35
2	Melamanakudi	49	43	20	25	137
3	Kesavanputhanthurai	0	1	0	0	1
4	Azhikkal	16	25	6	10	57
5	Rajakkamangalam	2	0	0	0	2
6	Pallam	4	1	1	0	6
7	Vaniyakudi	0	1	0	4	5
8	Kadiapattinam	6	2	15	8	31
9	Muttom	6	9	10	24	49
10	Chinnavilai	3	0	0	0	3
11	Periyavilai	1	2	1	0	4
12	Puthoor	13	4	4	3	24
13	Colachel	37	70	51	49	207
14	Kottilpadu	28	49	60	73	210
15	Kurumbanai	1	0	0	0	1
16	Ramanthurai	0	1	0	0	1
17	Enayam	0	1	1	0	2
18	Enayamputhanthurai	1	0	1	0	2
19	From Other Districts	3	1	1	4	9
20	From Other States	2	2	2	0	6
21	Unidentified	14	10	5	3	32
	TOTAL	196	238	182	208	824

Table 6.3.5 Social Status in Fishing Villagas in Tamilnadu

Name of the District (City)	Population Density in District	Population Density in Fishing Villages	Literacy Rates in District	Literacy Rates in Fishing Villages	Sex Ratio in District	Sex Ratio in Fishing Villages
Chennai City	-	-	80	68	951	944
Cuddalore	626	1412	72	59	985	946
Nagapattinam	548	849	77	57	1014	955
Kanyakumari	992	3858	88	78	1013	942

*Sex ratio shows number of women per thousand population.

(From: Frontline, Feb. 11, 2005)

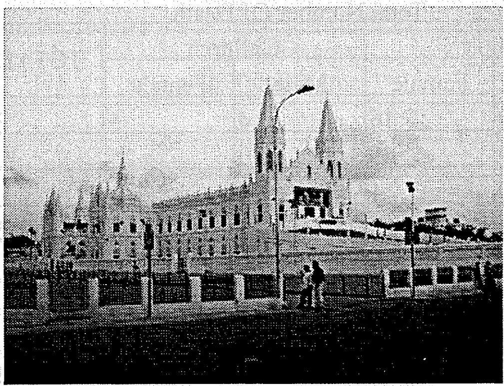


Photo 6.3.2 Church of our Lady of Health, Velankanni

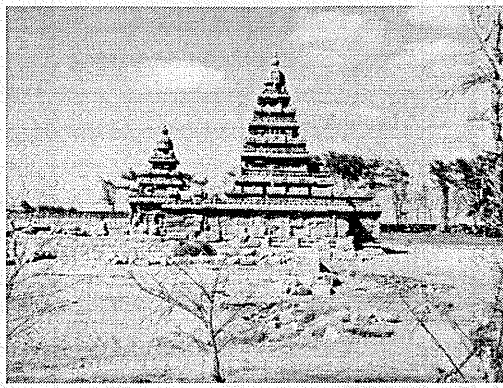


Photo 6.3.3 Shore Temple, Mamallapuram

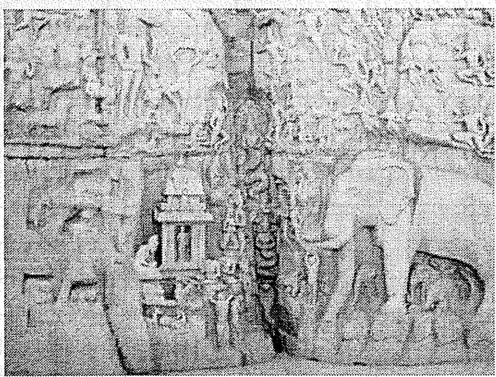


Photo 6.3.4 'Descent of the Ganga', Mamallapuram

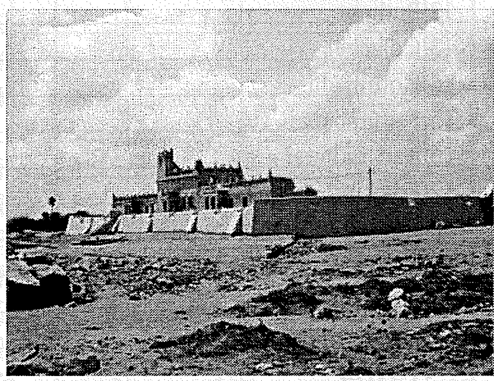


Photo 6.3.5 Dansborg Fort, Tarangambadi


Photo 6.3.6 Masilamaninathar Temple, Tarangambadi

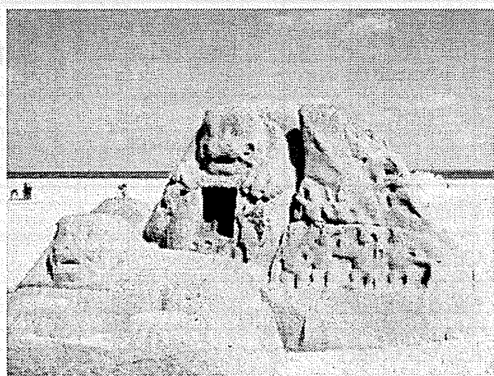


Photo 6.3.7 'Durga Rock', Mamallapuram

Acknowledgements

Field research was carried out in the tsunami affected areas of Tamilnadu, India, from Feb. 20th, 2005 to Feb. 28th, 2005 [for Y. & S. Sugimoto] / Mar. 5th, 2005 [for Fukao]. In India, we owe debt to Dr. S. Subbiah, Retired Professor, Dept. of Geography, Madras University, Chennai (Former Visiting Professor, National Museum of Ethnology, Japan), and to Mr. A. Sagayaraj, Ph.D. Scholar, University of Delhi, Delhi. We highly appreciate their valuable assistance and support for our research work.

Appendixes:

(1) Field Research Schedule:

Feb. 20th: Arrived at Chennai via Singapore

Feb. 21st: Visited (1) Consulate General of Japan, Chennai, & (2)Elliot Beach

Feb. 22nd: Arrived at Thanjavur via Trichy, visited (1) Dept. of Disaster Management, Shanmuga Arts, Science, Technology & Research Academy (SASTRA) Deemed University, Thanjavur, & (2) Spatial Information Technology for Disaster Management Course, Post Graduate and Research Dept. of Geography, Government College, Kumbakonam

Feb. 23rd.: Arrived at Nagapattinam, visited (1) Communist Party of India (Maxist) (CPI(M)), Nagapattinam Office, (2) Ariyanattu Teru, (3) Keechankuppam, (4) Akkaraipettai in Nagapattinam, & (5) Velankanni

Feb. 24th: *After Feb. 24th, we worked in two groups.

[Y. & S. Sugimoto] Interview with (1) Father V. Adaikkalaraj, Thanjavur Multipurpose Social Service Society (TMSSS), Church of Our Lady of Health, Velankanni, (2) Mr. M. Das, CPI(M), Velankanni, (3) Mr. Rajendra, Shipyard Owner, Seruthur, (4) Mr. Swaminathan, Fisherman, Seruthur, (5) Mr. Marimuttu, STD Booth Owner, Seruthur, (6) Mr. C. Rajachandra Mohan, Indian Overseas Bank, Nagapattinam, & (7) Sister Shanti, St. Anthony School, Nagapattinam

[Fukao] Visited (1) All India Radio, Karaikkal, (2) Tarangambadi (Tranquebar), & (3) Poompuhar on the way from Nagapattinam to Cuddalore

Feb. 25th: [Y. & S. Sugimoto] Visited (1) Nagore, & (2) Nagapattinam, interview with (1) Mr. S. Selvaraj, Auto Rickshaw Driver, Nagapattinam, & (2) Sister S.R. Viji, Daughter of Mary Immaculate (DMI), Nagapattinam

[Fukao] Interview with (1) Mr. M. Maruthavanan, Indian Overseas Bank, Cuddalore, (2) Mr. Balki, Tamilnadu Science Forum, Cuddalore, (3) Mr. M. Nizamudeen, Federation of Consumer Organizations-Tamilnadu and Pondicherry (FEDCOT), Cuddalore, & (4) Mr. K. Thirunavukkarasu, FEDCOT, Cuddalore, visited (1) Thazhanguda, (2) Arikamedu, (3) Samiyarpettai, (4) Pudukuppam, & (5) Devanamppattinam

Feb. 26th: [Y. & S. Sugimoto] Arrived at Chennai, summarized collected information

[Fukao] Arrived at Thanjavur, summarized collected information

Feb. 27th: [Y. & S. Sugimoto] Meeting with Dr. Subbiah, left Chennai for Japan via Singapore

[Fukao] Contacted with relevant persons, left for Kanyakumari via Trichy

Feb. 28th: [Y. & S. Sugimoto] Arrived at Kansai Airport, Japan

[Fukao] Arrived at Kanyakumari, visited (1) Melamanakudi, (2) Chothavilai, (3) Muttom, & (4) DMI, Rajakkamangalamthurai

Mar. 1st: [Fukao] Visited (1) CPI(M), Nagercoil Office, (2) Kottilpadu, (3) Colachel, & (4) Presentation Convent, Colachel

Mar. 2nd: [Fukao] Left for Chennai via Thiruvananthapuram

Mar. 3rd: [Fukao] Visited (1) Srinivasapuram, Chennai, & (2) Mamallapuram

Mar. 4th: [Fukao] Summarized collected information, left Chennai for Japan via Singapore

Mar. 5th: [Fukao] Arrived at Narita, Japan

(2) Informants:

(i) Dr. G. Victor Rajamanickam, Dept. of Disaster Management, SASTRA Deemed University, Thanjavur

(ii) Prof. R.H. Anand, Post Graduate and Research Dept. of Geography, Government College, Kumbakonam

(iii) Mr. M. Veeramani, Reporter, CPI(M), Nagapattinam

(iv) Father V. Adaikkalaraj, TMSSS, Velankanni

(v) Mr. M. Das, Secretary, CPI(M), Velankanni

(vi) Mr. Rajendra, Shipyard Owner, Seruthur

(vii) Mr. Swaminathan, Fisherman, Seruthur

(viii) Mr. Marimuttu, STD Booth Owner, Seruthur

(ix) Mr. C. Rajachandra Mohan, Branch Manager, Indian Overseas Bank, Nagapattinam

(x) Sister Shanti, St. Anthony School, Nagapattinam

(xi) Mr. S. Selvaraj, Auto Rickshaw Driver, Nagapattinam

(xii) Sister S.R. Viji, DMI, Nagapattinam

(xiii) Mr. M. Maruthavanan, Indian Overseas Bank, Cuddalore

(xiv) Mr. Balki, Tamilnadu Science Forum, Cuddalore

(xv) Mr. M. Nizamudeen, General Secretary & Chief Executive, FEDCOT, Cuddalore

(xvi) Mr. K. Thirunavukkarasu, Director, Local-Self Governance, FEDCOT, Cuddalore

(xvii) Mr. P. Navamani, Reporter of Theekadir, Thiruthuraipoondi

(xviii) Sister Diana, DMI, Rajakkamangalamthurai

(xix) Mr. S. Nurmohammadu, District Secretary, CPI(M), Nagercoil

(xx) Sister Savior, Presentation Convent, Colachel

(xxi) Mr. Kazumasa Wada, Ph. D. Scholar, Anna University, Chennai (residing at Mamallapuram)

(xxii) Dr. Alok Tripathi, Dupety Superintending Archaeologist, Underwater Archaeology Wing, Archaeological Survey of India, New Delhi

(3) Materials we obtained:

(i) Cunami: or ariviyal parvai, Tamilnatu Ariviyal Iyakkam, Maturai 2005 (Tsunami: a scientific view, written in Tamil)

(ii) Jan Kennati, S.M. & A. Celva; Cunami: or eccarikkai, Vaikaraip Patippakam, Tintukkal 2005 (Tsunami: a warning, written in Tamil)

(iii) Cunamiyal patikkappatta makkalukkaka veliyitappattulla aracanaikalin tokuppu, Cakaya Pilomin Raj, A. & Ku. Na. Pakatcin eds., A. Cakaya Pilomin Raj, Nagappattinam [2005] (Compilation of Government Orders for the people affected by tsunami, written in Tamil)

(iv) The First Tsunami in Kanyakumari, Uma Studio, Kanyakumari [2005] (Video CD)

6.4 Socio-Cultural Impacts and Responses in Sri Lanka Southern Coastal Area

6.4.1. Tsunami Disasters in Sri Lanka

The tsunami struck a relatively thin but extremely long coastal area stretching over 1,000 kilometers, or two thirds of the country's coastline. The damage stretches from Jaffna in the north down the entire eastern and southern coast, and covers the west coast as far north of Colombo as Chilaw. It did seriously damage to not only coastal belt but also inland area. The deadly Tsunami killed not only fisher folk but also people who lived or stayed along beach line or happened to pass by the coastal road. The hit of huge wave caused damages to fishery, tourism and other industry such as coconut coiling, salt manufacture as well as commercial business. It must take many years to reconstruct the economy and infrastructure of entire Sri Lanka. She is forced to have another serious problem though first problem, namely Peace Process, has not been solved. Now in Sri Lanka there are two rehabilitation programs from man-made disasters and natural disasters.

The day Tsunami hit was Sunday, *POYA* (full-moon day which Buddhist refrain from fishing) and the next day of X'mass. On Sunday people enjoy shopping at Sunday *POLA* (Market or Bazaar). In Matara Town, Hambantota Town and other big towns, people gathering at or going to *POLA* opened near the beach were swallowed and carried away by the huge waye. People staying at beach resort and refreshing in the beautiful Indian Sea breeze, taking trip bound for the sacred temples and churches by trains, buses or their own cars, all were affected by killing Tsunami.

In North and North-East of Sri Lanka, fisher-families had started new life after a long period of refuge because of civil war in the Region. They came back from shattered place and started fishing again. Not only fisher-families but also people engaged in other occupations had peace after more than 20 years war. In these areas Tsunami knocked their life down. Most of buildings and houses which were damaged were built or renovated very recently after Peace Process started.

Photo 6.4.1 A place of national collective tragic memory is now becoming a pilgrimage spot (a eight-career train with full of passengers bound for Matara was swallowed by the tsunami and hundreds of passengers were killed), near Induruwa in Galle District

6.4.2. Outline of impact and damage in Sri Lanka

Sri Lanka has population of more than 19,000,000. Due to Government and other official reports, it is recorded that more than 30,000 people were killed, 23,176 were injured and 4,698 were missing. Almost 100,000 houses were fully destroyed and about 50,000 were partly damaged. 834,849 persons were displaced (5th January, 2005 report), about 500,000 persons are still in welfare centers or in the houses of relatives and friends. Tsunami also killed a lot of fishermen who were staying on the beach or on board for landing. According to Ministry of Fisheries and Aquatic Resources and FAO, more than 7500 fishes (fishermen including their family members) were killed. 80% of coastal fishing vessels were completely or very seriously damaged. 10 harbors with modern facilities out of 12 were affected. There are almost 110,000 marine fishermen, so nearly 1%fishermen's lives were lost.

Table 6.4.1 shows the numbers of affected families, people injured and missing, death of people and death numbers of fishermen . Obviously people in the East (Hmbamtota, Ampara, Batticaloa and Trincomalee) are terribly affected.

Table 6.4.1 affected families and people ,death total of fishermen* at 23rd January 2005

District	affected fami	displaced fa	injured	missing	death total	death of fish
Jaffna	13,652	12,631	1,647	540	2,640	926
Kilinochchi	2,295	318	670	1	560	11
Mulaittivu	n.a.	6,007	2,590	552	3,000	2,524
Mannar	0	0	0	0	0	0
Puttalam	232	18	1	3	4	0
Gampaha	6,827	52,58	3	5	4	3
Colombo	9,647	5,290	64	12	79	1
Kalutara	6,064	6,105	400	148	256	17
Galle	23,174	1,562	313	554	4,214	64
Matara	20,675	3,268	6,652	613	1,342	331
Hambantota	16,944	3,334	361	963	4,500	365
Ampara	38,624	n.a.	120	876	10,436	1,025
Batticaloa	63,717	12,494	2,375	1033	2,840	1,229
Trincomalee	30,102	27,746	n.a.	337	1,078	725
Total	232,677	84,031	15,196	5,637	30,957	7,222

* The numbers are changing according the time investigated and different due to the Ministries and Organization, I use two sources with reference to Ministry of Fishery and Aquatic Resources and

National Disaster Management Center. Data was collected by each District so we can not say all data is correct.
n.a.:No Answers

Tsunami affected areas are fascinating famous beach resort ,so tourists and surfers from all over the world enjoyed staying, swimming, surfing or just relaxing in from luxurious hotels to neat and cheap guest houses. Killing wave destruct accommodations without any distinction . Table 6.4.2 shows the hotels affected by Tsunami. Reports on damage to guesthouses are not available, however, it is sure that many such guesthouses and rooms are heavily damaged because I saw, for example, in Unawatuna in Galle District, rubbles and debris along shore line where comfortable guesthouses and sea-food restaurants used to stand on before Tsunami.

After Tsunami, accommodations, restaurants and souvenir shops which were survived from severe destructive wave started business again, but they had to be confronted with other disasters, namely, a fall of the numbers of tourists. When I walked along main street in Hikkaduwa where hotels, guesthouses, restaurants and souvenir shops lined without break before Tsunami, I saw only a few tourists and employees. This area used be one of most energetic spot full of international tourists

Table 6.4.2 Status Report of Tourist Hotels as of 13th January 2005**

District	Hotels Total	Rooms Total	Closed Hotels	Closed Rooms
Jaffna	no data			
Kilinochchi	no data			
Mulaittivu	no data			
Mannar	no data			
Puttalam	no data			
Gampaha	32	1,735	0	0
Colombo	37	3,295	0	0
Kalutara	26	1,745	9	714
Galle	49	2,446	22	1,536
Matara	7	253	6	193
Hambantota	16	573	5	233
Ampara	2	32	2	32
Batticaloa	no data			
Trincomalee	7	260	5	227
	176	10,339	49	2,935

Source Tsunami Information Management Center

** North and North-East have originally no data as all the hotels were closed because of civil war. Hotels located in Up-countries where no tsunami wave affected the buildings are omitted.

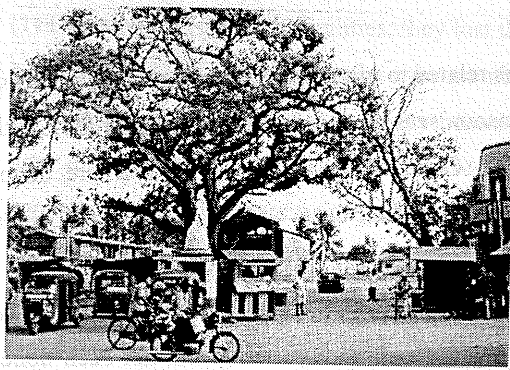


Photo 6.4.2 Wholesale market and a small Stupa under a huge tree in 1985

Photo 6.4.3 The same place after the tsunami, March 2005

6.4.3. Fishery in modern Sri Lanka

People living along coastal belt have long been engaged in fishing. When we discuss about the Tsunami damage to fisheries and fishermen, several distinctive features can be pointed out.

(1) Since 1970s', due to fishery progressive plan, the supply of mechanized boats with in-board engine has started and fishery harbor construction program at several places around Sri Lankan Shore Line has begun. Besides, since 1980s', bigger size multi-day boats (they are called ice tank boat) have been provided. Then boat owners and crew fishermen go fishing from fishery harbors instead of from the beaches where they live.

(2) Mostly fishermen have no fishing gear, so they go to sea by someone's boat or becoming crew members of modern boats if they want to go fishing.

(3) Development policy towards fishing communities are planned and carried into effect through fishery co-operative societies organized in each administrative village.

(4) Mostly boat owners borrow money from fish merchants or wholesalers, they give fish to merchants for consigns, meaning loan repay. They are paid after deducting debt.

(5) Fishermen have migrated during monsoon period, for example, those who live along south or south-western coast move to eastern coast during South-western monsoon season. Since new fishery harbors have developed, they go to these harbors all year round. As the numbers of multi-day boats (ice tank boats) have increased, fishery harbors have been more and more equipped with boat yard and ice-factory and repair shops, so fishery harbors located at eastern coast, for example, Trincomalee and Kirinada, are easy to anchor even during north-east monsoon season. Now boat owners prefer anchoring their boats at these harbors, so many fishermen and fish merchants come to these harbors to search for good business chance.

(6) Migratory harbors and traditional migration beach are usually located in Tamil speaking area. During civil war south and south-western fishermen were affected ethnic problems. Still some area

along east coast is in high security zone, so fishing activities are very much restricted.

The fact that, in Sri Lanka, fishing activities is related to migration, so it makes their situation more complicated. December is north-western monsoon season, so a lot of fishermen of the South are staying at newly constructed fishery harbors like Galle, Beruwara, Hikkaduwa where better equipment is provided. Also some of them were anchoring their boats at Torincomalee or Kirinda where even during north-east monsoon season, mechanized boats can be operated.

Usually boats are registered at the District Fishery Office where they live in, but they are mostly operated on a different sea and anchored at the port where registration has not been done. And it is very normal that boat owners prefer their relative persons operating the boat in the name of owners. So the damaged boats were operating or mooring on different ports or landing centers from where they were registered.

As fishermen who were killed by Tsunami in the place of migration, the procedure of the issue of the death certificate takes time with complicated procedures.


Photo 6.4.4 Galle Road near Hikkaduwa


Photo 6.4.5 A beach near Hikkaduwa

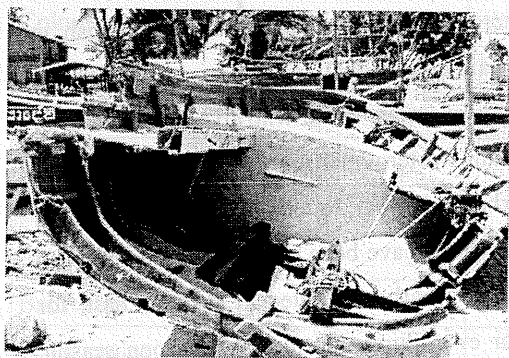


Photo 6.4.6 A wreck of motor boat on a residential street in Ambalangoda


Photo 6.4.7 Wrecks of houses and temporal housings on a residential street in Ambalangoda

People living coastal belt were damaged by Tsunami at following three points

(1) Damage of production facilities: they lost their boat, fishing equipment and landing place as well as fishermen lost their chance to be crew members.

(2) Damage of living conditions: many houses were damaged completely or partly, so residents are now in refugee camps or relative's houses. After Tsunami, new building structure will not be permitted within 100 meters (200meters in the eastern coast). People can not make decision to start building new houses, and it will be difficult to find new land to build houses for refugees. So they will be compelled to stay in uncomfortable refugee camps or relative's houses for an indefinite period.

(3) Damage by rumor: after Tsunami some went sea to earn money, but the amounts of fish consumption decreased because consumers hesitated to eat fish. There was groundless rumor that fish eat dead person's body. There was dead stock for 2 to 3 weeks after Tsunami even in Central Fish Market in Colombo although many fish were brought from non-Tsunami affected fish landing centers such as Negombo. This rumor discouraged fishermen from starting their daily activities.

6.4.4. Aid for the Tsunami affected fisher-families in a case of a Southern Coastal Village

The degree of damage and influence is somehow different among the places where they locate. Now I consider one village which located at Southern Coast. This village named T(anonymous) has affected rather less than other marine villages, that means ,numbers of destroyed houses, displaced families, dead persons are rather small compared with other villages. If you visit T village after visiting other totally damaged villages, you find the scene different from those completely destructed ones even though some houses near the beach were washed away. But this fact doesn't mean the villagers are slightly escaped from Tsunami disaster. There are some invisible damages in such village.

The Plan for the aid toward the affected families which live in maritime area has been operated with premise that all the fisher families living along coastal zone suffered damage. So all the fisher-families can receive 5000Rs per month (4500Rs cash, 500Rs deposit), everyone in a fisher-family can be provided 375Rs per week(200Rs cash ,175Rs food-rice or flour, Dahl and sugar-).

Administratively restoration and support plan was carried out through GS (Grama Sewaka which means village-level administrative office) to AGA (Assistant Government Agent ,recently changed name to DS =Divisional Secretariat).

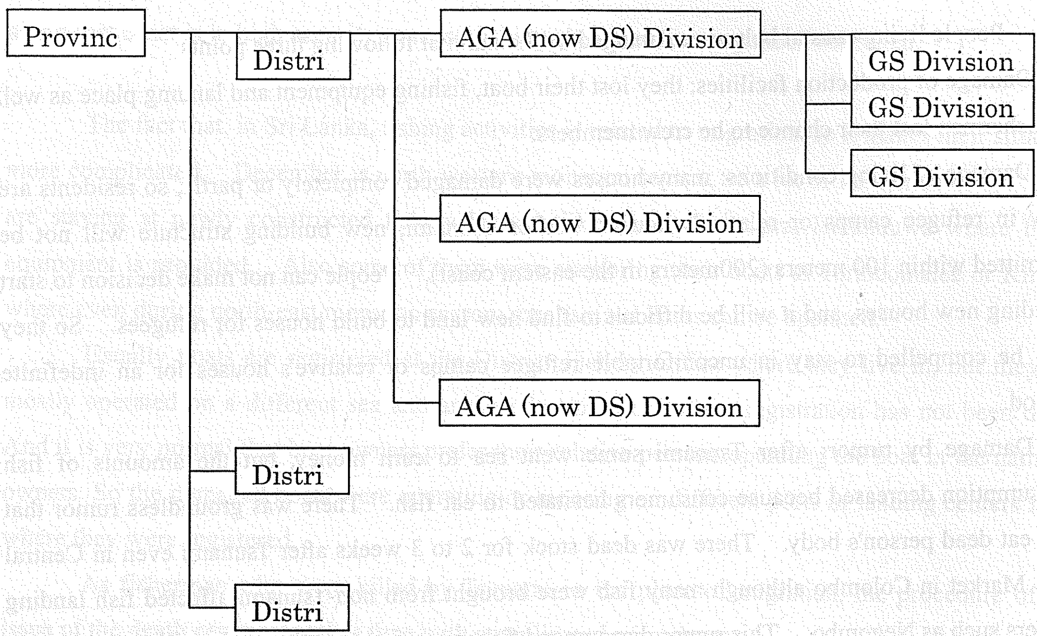


Figure 6.4.1 Local Administrative Formation in Sri Lanka

The Aid was done according to following process.

(1) AGA Office specified the numbers of families which needs aid in each village (GS Division). In a case of 'T' GS Division (anonymous Village name) where I have done village level research, AGA office designated the numbers 250 households

(2) Excluded households from the financial support are-

1) non-fishery household
2) household whose member is engaged in public or civil service
3) household whose member is engaged in a foreign country

(3) Inspectors appointed by AGA office carried out whole village survey and found out that more than 250 households suffered disasters, they found that type 2 and type 3 households are also affected Tsunami disasters.

(4) AGA made a decision according to the report of inspectors that numbers of households which needs aid was increased up to 340 as well as family type 2 and 3 can be provided financial support

(5) Inspectors identified and reported the affected families to GS officer, however, he ignored the report, and what is worse GS officer reported to AGA office false statement.

This happens very often in Sri Lanka that administrative plan has not been operated reliably in each local level office or officers.

(6) Most T villagers distrusted the GS officer, so he was removed from the position and new officer

was appointed.

(7) Because of these confusions, the next donation was delayed .They couldn't get support service more than two months.

This confusion is mainly based on the situation of coastal communities related to a kind of chaos after Tsunami but partly on their perception about their daily economic activities. Firstly, it is difficult to identify which is the fisher-family. When fishery co-operative society plan was set about in 1970s', the urgent purpose was to organize society as soon as possible along coastal zone and to increase the numbers of membership as many as possible. After 30years, however the society was re-organized several times, fictitious members or those who lost membership have been increased since there is hardly advantage and benefit of being member.

Not all the inspectors as well as GS officer are familiar with villagers, and not all the fishermen are the members of the co-op society. So AGA decided to give financial support to fisher-families whether they are the member of co-op society or not. After Tsunami, villagers say, the numbers of fisher-families increased rapidly, they showed the old broken fishing gears or big pan for making processed fish to prove that "We are fishermen, We are fisher-family".

If they have fishing boats or if they are fish-merchants, they are absolutely fisher-family members, but in Sri Lanka, most people whose income is from the sea don't have any boats or fishing gears. They goes to the sea by someone's boat or by being crew members of someone's boat because they can not get any job ,so if they luckily find out any job ,soon they stop going to the sea.

Aid was provided through fishery sectors, so they had be fishermen or member of fisher-family because of urgent demand to survive after they survive from the natural disaster. Not like rich or middle-class families, people with bad economic conditions have to find chance to get financial support as non-fisher families without any occupations were ignored.

Other confusion is related to their migration custom of their fishing activities. Many owners lost or damaged their boats outside where they registered as well as many were killed outside the village where they lived. Also complicated procedure to get financial aid discouraged them. They had to go far away from their home to other district office in order to get certification to prove the damage of their boat, so they spend time and money. Compensation is provided only the boat completely destroyed, so half-destroyed boat is excluded from compensation, at the same time the parts like out-board engine or fishing net are also excluded from the aid objectives. Some boat owners repaired their boat or found out parts washed away spending lot of money because they needed to start fishing again. These cases mean they can not get any compensation since it is difficult to prove the damage degree.

Widow is the same, her husband was killed at the harbor outside the village, so it takes time to get death certificate. She has to go far away by bus spending bus fare to get certification in order to receive allowance provided for the family whose householder died.

Many families living in temporary houses can not see their future living conditions since Government restricted to rebuild houses within 100metres (200 meters in the Eastern Coast) of coast line (except commercial and fishery harbors and religious structures). New land to build houses for the families whose houses were damaged or lost by Tsunami has not been found out yet. They may still have to continue living in deadly hot and stuffy tents provided by NGO.

6.4.5. Conclusion

Sri Lankan people had never considered terrible natural disasters like Tsunami hit to their land by the time it really came. But they had already suffered many man-made disasters. The worst natural disaster in Sri Lankan history can not be compared with these man-made disasters, but they are trying to overcome this unexpected cruel fact as they have already done. The difference from other disasters which they have already experienced is that this disaster is very much related to Sri Lankan political and social situations. The most severely affected areas are the stages of brutal civil war between Government and anti-Government militant group, between two political sects of anti-Government group involved other religious ethnic group. In the South, people were not involved in this type of disaster entirely, however, their migration to the East Coast was much restricted during War time and Indian Peace Pact stayed around 1987. Southern people suffered tragic JVP insurgency in the latter half of 1980's.

After Peace Process started a lot of NGO came to Sri Lanka, besides that after Tsunami more and more NGO started aid services. Some groups and organization have started activities without knowledge of culture, history or political situation. So there is a dangerous possibility that some NGO activities will reinforce the tension among these political groups or break the balance kept among them.

People have already started reconstruction and rehabilitation of life by themselves since there are intimate human networks spread over the almost whole country. So the most important thing is to prevent any intervention of political groups whose desire is to expand and increase their political power. In Sri Lanka, normally religious organizations are rather neutral though some Buddhist monks are political with Sinhala ethno-centric Nationalism, so temples, churches , mosques can be the regional centers of integration. At least they have already played roles in mental healing. In many places, village level or local level NGO has been acting and a kind of patron-client relationship is functioning to support the families which need any help. Huge sum of money granted to Sri Lanka must be used for developing the mechanism of these local activities. There are big NGO like SARVODAYA, SEWALANKA and TECH etc., so some organizations to connect these NGOs are necessary as well as local-level detailed research.

Sri Lankan rehabilitation plan is carried out by bureaucratically, though many people included public services are disappointed with present Government which has given up Peace Talk with anti-Government Tamil political group(LTTE). So the political situation will be worse if foreign peace mission stop acting as mediator. Again Sinhala ethno-centered political party has begun political campaign against the Peace Process taking advantage of this confusion. So not only Tsunami rehabilitation but also the future of Peace Process must be paid attention carefully. Otherwise regional or ethnic gap will be more and more spread and what is worse, the cease-fire might be broken again.

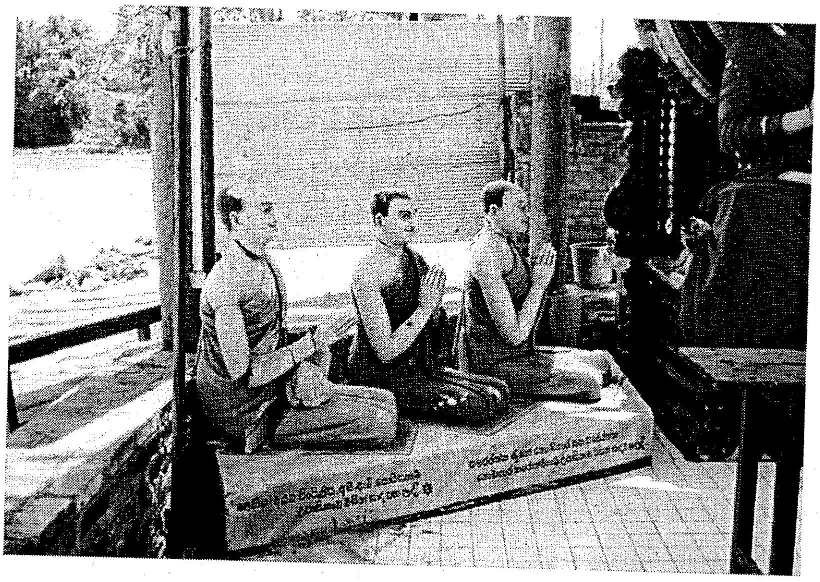


Photo 6.4.8 Temporary repairs in a temple located along the beach in Kottegoda

Acknowledgements

The field research and data collection in Sri Lanka was carried out from 12 March to 21 March 2005. Both in Japan and in Sri Lanka, many people extended their friendship for my research; particularly I owe debt to Prof. K. E. Karunaratne and S. Gunasekere of University of Colombo, as research counterparts, and to Mr. J. A. Nandana Jayakody of Daito Bunka University, for their help and encouragement.

Chapter 7 Information Sharing on Indian Ocean Tsunami Disaster - Web site development on "The December 26, 2004 Earthquake Tsunami Disaster of Indian Ocean2004 "

7.1. Introduction

Sumatra Earthquake on Dec.26, 2004 and earthquake induced tsunami caused devastating damage to countries facing to Indian Ocean. Various international organizations worked for emergency response, relief, and recovery activities in Indonesia, Thailand, Sri Lanka, and India. There were portal sites for information sharing on EMERGENCY ASSISTANCE. Web site of United Nations Office for Coordination of Humanitarian Affairs (OCHA) which called "Reliefweb" (Fig.1), http://www.reliefweb.int" and International Federation of Red Cross and Crescent Societies, http://www.ifrc.org/, were major web sites for information sharing on emergency assistance. However, in this event, sites for "facilitating information exchange among all humanitarian actors, including among UN agencies, government and other national entities, donor governments and agencies, national and international non-governmental organizations and civil society" were established in "The Humanitarian Information Centre (HIC) (Fig.2)", http://www.humanitarianinfo.org, which is oriented information sharing on long term assistance and also managed by OCHA. In addition to those web sites managed by international organizations, each local government established their own web sites. For example, Indonesian government established web site called "E-Ache", http://www.e-aceh.org/, to share information on reconstruction.

Now a web site has become key tool for information sharing and various web sites to coordinate victims assistance and disseminate information to impacted people has established. However, information sharing from academic society which makes intensive survey on hazard mechanism, damage, and disaster response is limited. According to those backgrounds, our research group decided to establish a web site to share information collected through field survey and numerical analysis. Targeting audience of the site is general public but this site is also used information sharing among researchers.

URL of this site is http://www.drs.dpri.kyoto-u.ac.jp/sumatra/index-e.html and managed by the collaboration with Research Center for Disaster Reduction Systems, Disaster Prevention Research Institute, Kyoto University.

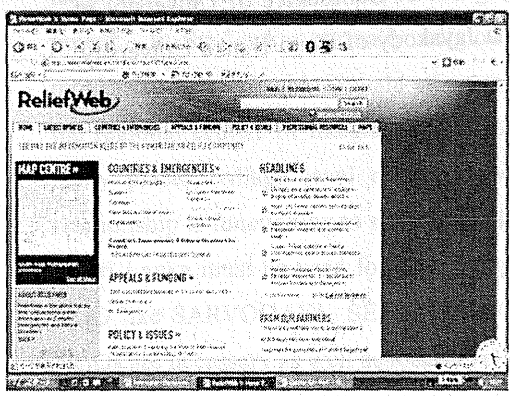


Fig.1 Reliefweb

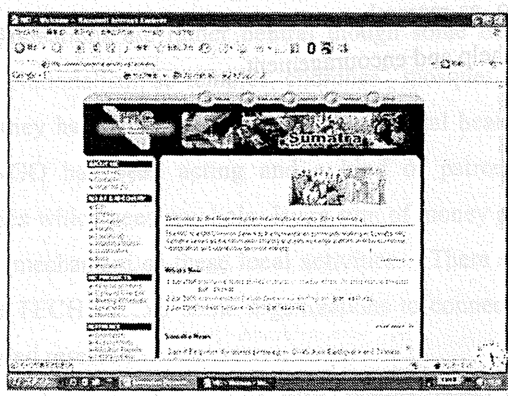


Fig.2 The Humanitarian Information Centre (HIC)

7.2. Structure of the web site

Contents of this web site are consisted from eighteen main categories such as (1)Earthquake Information, (2)Tsunami Information, (3)Modeling, (4)Photo/ Image Database, (5)Maps, (6)Survey, (7)Survey Results, (8)Conference, (9)Regional Information, (10)Resource, (11)Damage, (12)Witness and Experience, (13)Web Article, (14)International Relief, (15)Media, (16)United nations, (17)Countries, (18) Links. Each main category has several sub-categories under that. Contents on this web site can be categorized into eight categories,

1) Hazard information: (1)Earthquake Information, (2)Tsunami Information, (3)Modeling,

2) Socio-cultural information: (9)Regional Information

3) Damage information: (11)Damage

4) Survey report: (7)Survey Results, (8)Conference

5) Disaster response: (14)International Relief, (15)Media, (16)United nations, (17)Countries

5) Logistics: (18)Survey

7) Database: (4)Photo/ Image Database, (5)Maps, (10)Resource, (12)Witness and Experience, (13)Web Article

,and 8) Links with relating website: (18) Links

Fig.3 shows whole structure of this web site and Fig.4 shows Index page of this site. Detailed contents of each main category will be explained in the following chapters.

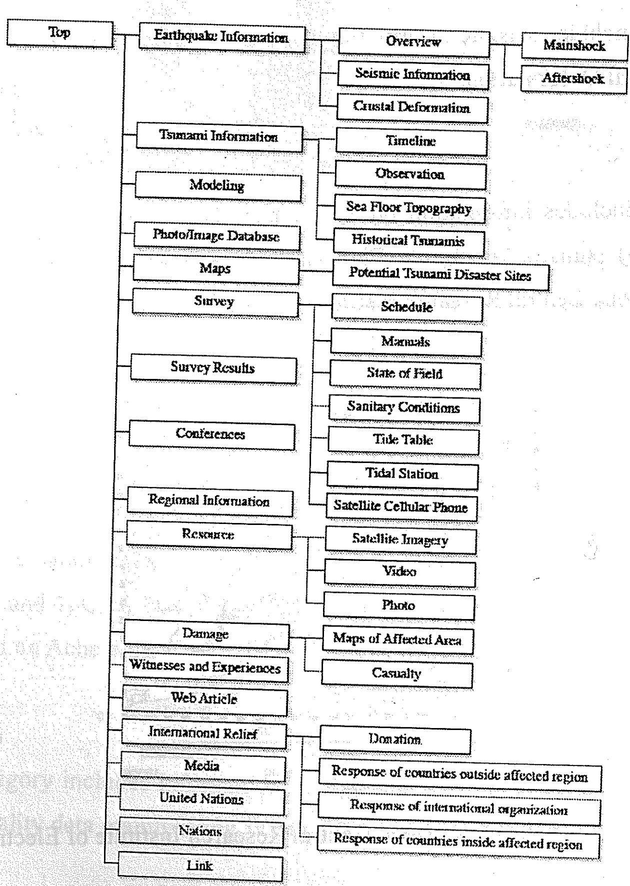


Fig.3 Structure of the web site

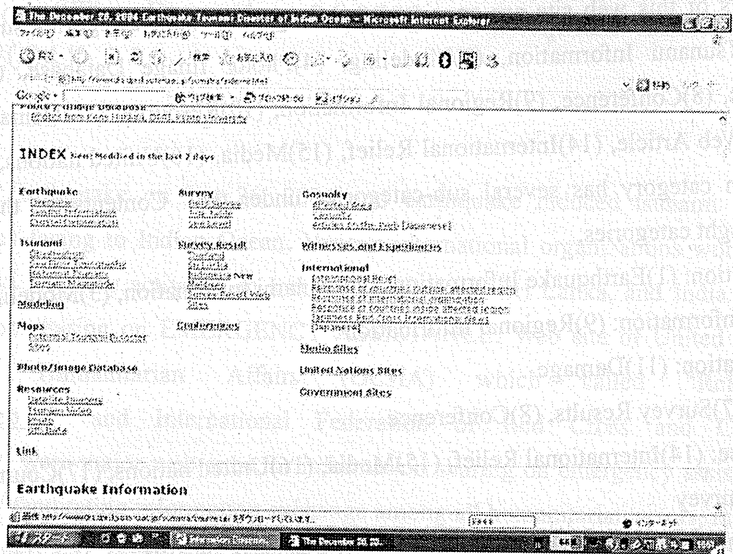


Fig. 4 Index Page

7.3. Hazard information

1) Earthquake Information

This category includes seismic information such as 1) Main shock and after shocks, 2) Seismic Information, and 3) Crustal Deformation.

2) Tsunami Information

This category includes information on 1) Tsunami Observation, 2) Sea Floor Topography, 3) Historical Tsunami, and 4) Tsunami Magnitude. Fig.5 shows one example of contents, sea floor topography distributed from Matsuyama, Central Research Institute of Electric Power Industry.

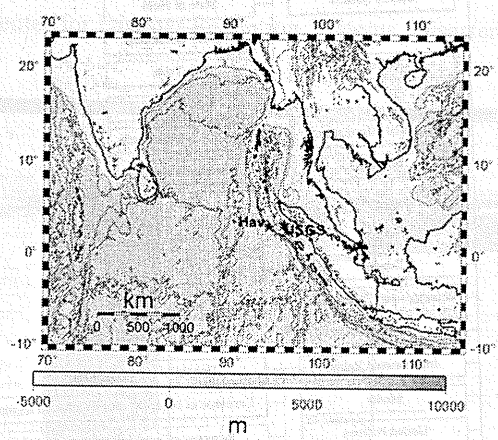


Fig.5 Sea Floor Topography from Matsuyama, Central Research Institute of Electric Power Industry

3) Modeling

This subcategory includes numerical tsunami simulation results by following eight researchers and research institute; 1) DCRC, Tohoku University: Modeling a tsunami generated by Northern Sumatra earthquake [12/26/2004], 2) Kenji Satake, AIST: Tsunamis in Indian Ocean from Sumatra Earthquake, 3) Vasily Titov, NOAA / PMEL: NOAA REACTS QUICKLY TO INDONESIAN TSUNAMI, 4) Ahmet Cevdet Yalciner, Middle East Technical University, Department of Civil Engineering, Ocean Engineering Research Center: The Model Studies on December 26, 2004 Indian Ocean Tsuanmi, 5) Andrey Babeyko, University of Frankfurt/M and Stephan Sobolev, GFZ Potsdam, Germany: A Numerical Simulation of the Indian Ocean Tsunami 26 Dec. 2004, 6) Nobuaki Koike, WNCT: Preliminary report of numerical computation of tsunamis generated by the December 26, 2004 Off Sumatra Island Earthquake, Indonesia, 7) Shunichi Koshimura, DRI: DRI Preliminary Tsunami Modeling Report, and 8) DRS, Kyoto University: Research Center for Disaster Reduction Systems Tsunami Modeling Report. Fig.6 shows simulation results by Kyoto University and DRI

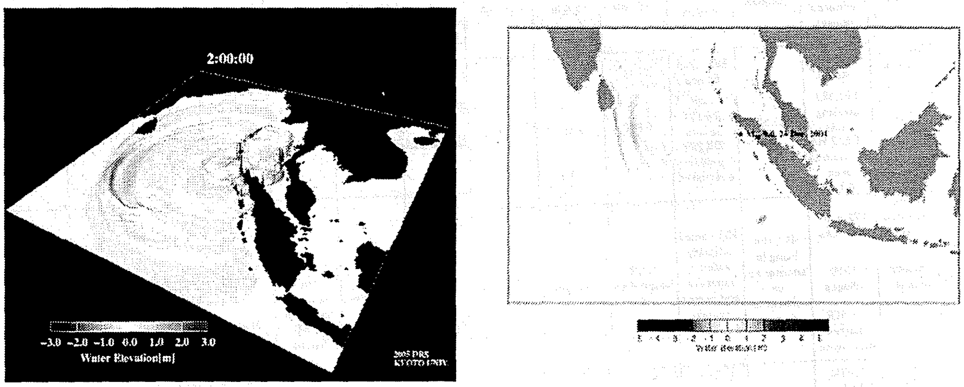


Fig.6 Numerical Simulation (Left: Research Center for Disaster Reduction Systems Tsunami Modeling Report, right: DRI Preliminary Tsunami Modeling Report)

7.4. Socio-cultural information

Socio-cultural information was summarized in "Regional Information" category. Our research group consisted from natural scientists, engineer, and social scientists. And group of social scientists who are mainly anthropologists and regional specialists contribute to collect cultural and social information of each impacted area. Information on 1) Relief, and recovery activates, 2) Reconstruction planning, 3) International Assistance, and 4) Civil War in Ache are distributed by the contribution of Dr. Yamamoto, Ms. Nishi, and Ms. Shinozaki on Ache area.

7.5. Damage information

"Damage" category includes information on damage maps and human causality. Table 1 shows summarized human causality data mainly using WHO information in "Damage" category.

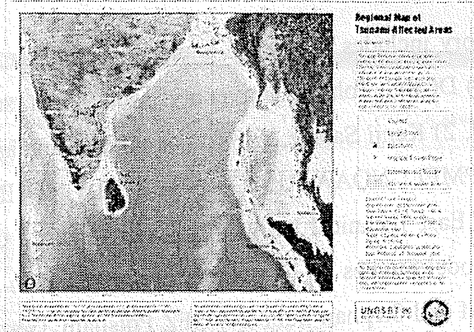


Fig. 7 Damage map by UNOSAT

Table 1 Human Causality based on WHO and various information sources

Country	Areas / people affected	Damage	Displaced Peoples	Relief	Injured	Missing	Deaths
Sri Lanka	12 coastal districts 103,789 affected families	103,753 affected houses	500,668	328 relief camps	15,196	5,644	30,959
India	2200 km of coastal land 300m-3km inland 3 million people	897 villages 157,393 dwelling units 11,827 HA of cropped area 1.56B USD	647,556	595 relief camps with 376,171 people 638,297 people evacuated	6,898	5,551	10,872
Indonesia	Aceh: Districts (14 out of 21): 1 million people	172 sub-districts 1550 villages 21,659 houses destroyed	417,124 living in spontaneous settlements	103 camps officially listed - numbers and camps remain fluid	1,736 hospitalized	127,749	101,199 buried
Thailand	6 provinces on west Thai coast with 308 12,068 households	6.85M Baht have been provided to assist victims		47,708 rescue workers mobilized	8,457	3,144	5,332
Malaysia	NW states of Penang and Kedah		8,000	30,000 in 9 camps	73 in-patient 694 outpatient	6	68
Maldives	20 atolls 100,000 people affected	3,997 buildings, including 30 health facilities at differing levels	10,578		1,313	26	83

Country	Areas / people affected	Damage	Displaced Peoples	Relief	Injured	Missing	Deaths
Myanmar	23 villages, 10-15,000 people affected long-5-7,000 directly affected	592 houses of 17 villages destroyed	2,592 homeless/ households (537)		43	3	61
Bangladesh							2 (1/3 16:00 CNN)
East Africa							136 (12/30 20:36 共同通信)
(Somalia)	Puntland region worst-hit,? 650 km of coastline	600 families have lost 2,600 fishing boats destroyed	Approx. 4,000	Many sheltering under plastic sheeting or in branch	NA	NA	At least 150
(Tanzania)							10 (1/3 16:00 CNN)
(Seychelles)							Unconfirmed reports of deaths (12/29 19:39
(Madagascar)							
(Kenya)							1 (12/29 19:39

7.6. Survey report

1) "Survey Results"

This category includes daily activity reports, survey results by our research group. Following series of filed surveys were conducted by our research group in Indonesia, Thailand, Sri Lanka, Maldives, and Myanmar. Fifteen research groups were conducted field survey in impacted area.

Indonesia: (1)January 17 - February 1, 2005 Banda Aceh, etc. , (2)February 8 - February 17, 2005 Nanggroe Aceh dar es salam, (3)February 11 - February 14, 2005 Banda Aceh

Thailand: (1)December 30, 2004 - January 4, 2005. Phi Phi Is., Phuket Is., Khao Lak, (2)January 28 -

January 29, 2005. Phuket, Phangnga Province, (3)February 24 - March 4, 2005.

India: (1)February 20 - March 5, 2005, (2)March 18 - March 27, 2005.

Sri Lanka: (1)January 4 - January 6, 2005. Galle, (2)②January 6 - January 9, 2005. Southern Coast, (3) February 23 - March 19, 2005, (4) February 25 - March 5, 2005. South Part, (5)March 12 - March 20, 2005.

Maldives: (1)January 27 - February 5, 2005.

Myanmar: (1)March 6 - March 18, 2005.

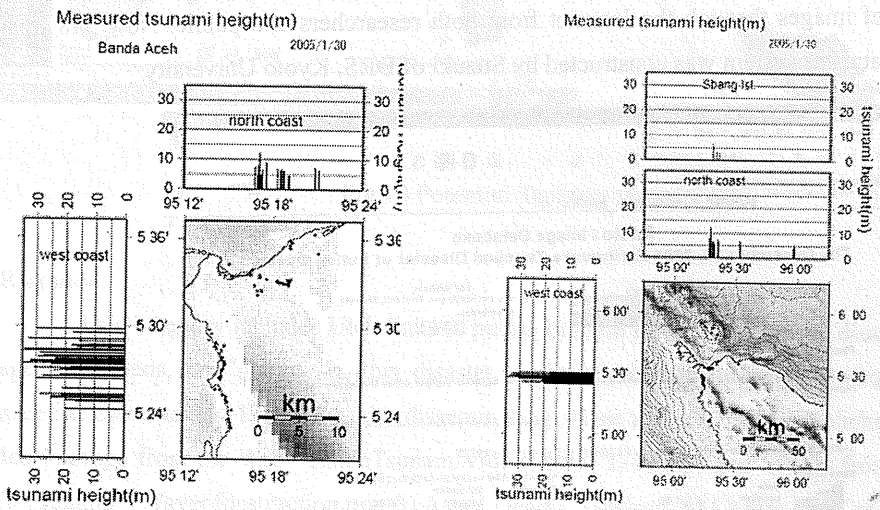


Fig.8 Field survey results from the Tsunami Survey Team (The Head: Dr. Tsuji)

<Indonesia: January 17 - February 1, 2005 Banda Aceh, etc>

2) "Conference"

This category includes schedule of symposium or workshops on Indian Ocean Tsunami disaster. Many researcher of our research group made a lecture on field survey results at symposium or workshops.

7.7. Disaster response

Disaster response activities were summarized in "International Relief" "Media", "United nations", "Countries" category. Following contents was included in this category; OCHA mid-term report, Monetary donation, Assistance from various countries, Assistance by international organizations, News from International federation of Red cross and crescent news, Report from Japan Emergency Assistance team.

7.8. Logistics

Logistics information for field survey was summarized in "Survey" category. Safety information was critical to conduct field survey in each impacted area, especially in Ache and Sri Lanka, where civil war has continued. Various information to support filed survey were summarized in this category such as 1) Schedule, 2) list of specialists on each impacted area, 3) Medical information, 4) Sanitary information,

5) Tide table of each area, 6) Tidal Information, and 7) Satellite mobile phone.

7.9. Database

Various information such as 1) Photos and Images, 2) Damage Maps, 3) Public domain resources: Satellite Imagery, Video, and Photos, 4) Interview to witness and on experience, and 5) Web article, collected through field surveys and researches were compiled into this web site as database.

1) Photo/ Image Database

Image database on tsunami disaster of Indian Ocean was established. This database is managed through subscription of images through the Internet from both researchers and public. Now 348 images have been installed. Database system was constructed by Suzuki of DRS, Kyoto University.

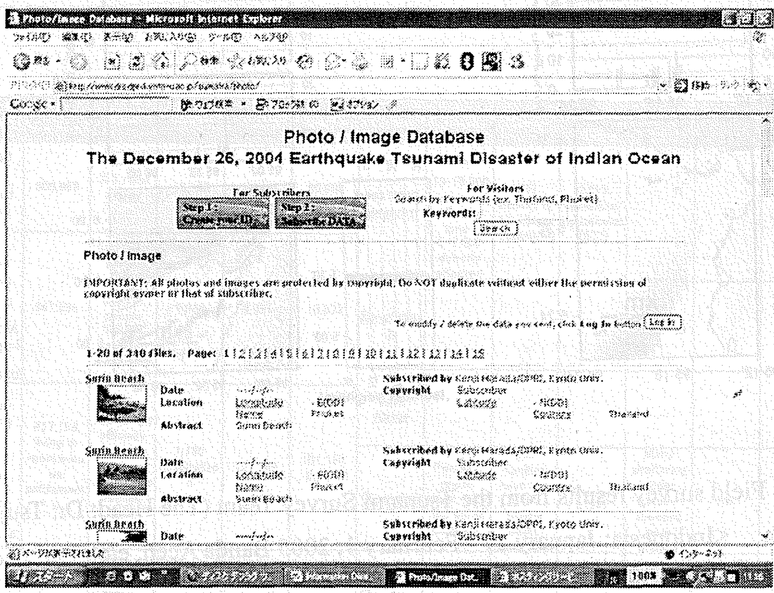


Fig.9 Image Database

2) Maps

"Map" category contains potentially tsunami disaster map. This map was created by combining the maximum water elevation obtained from Dr. Koshimura ュ s numerical simulation with the locations of human settlements by DMSP stable light imageries. A closer view with the resolution of 1/45,000 may be available for those areas where the estimated maximum water elevation exceeds 50 cm, and a list of the name of those cities. Another closer view with the resolution of 1/20,000 will be available for those areas where the estimated maximum water elevation exceeds 2m.

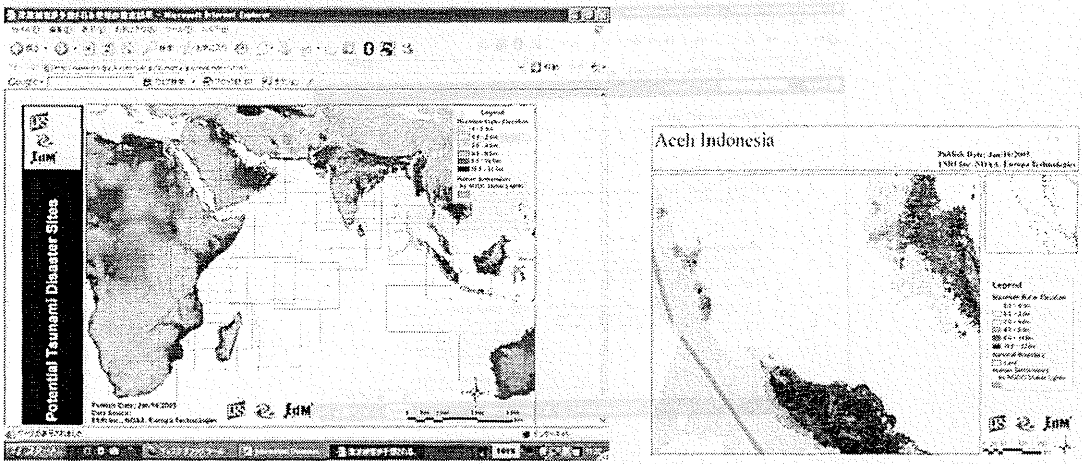


Fig.10 Potential Tsunami Disaster Site

3) Resource

This category includes URL links to public domain information on the disaster including satellite imageries, videos, and photos. In this disaster, various precious movies showing on how tsunami is destructive were taken. Following sits disseminating those movies were established; 1) Asian Tsunami Video Footage from the Web - AsianTsunamiVideos.com, 2) Photos and Videos from the aftermath of the Asia Tsunami - Waveofdestruction.org, 3) Asia's Deadly Tsunami, 4) Cheese and Crackers: Tsunami Video, and 5) Pundit Guy: Tsunami Video

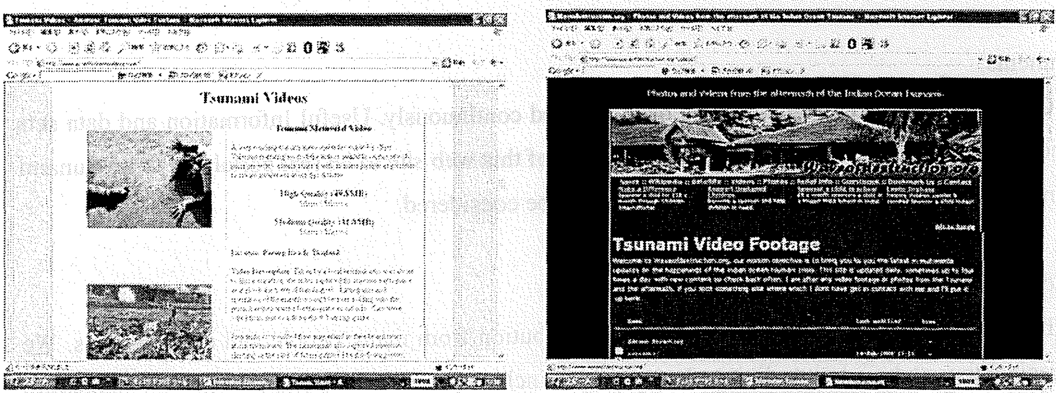


Fig.11 Tsunami videos download site (Asian Tsunami Videos.com and Tsunami Video Footage)

4) Witness and Experience

This category include URL link to ethnography of tsunami survivors.

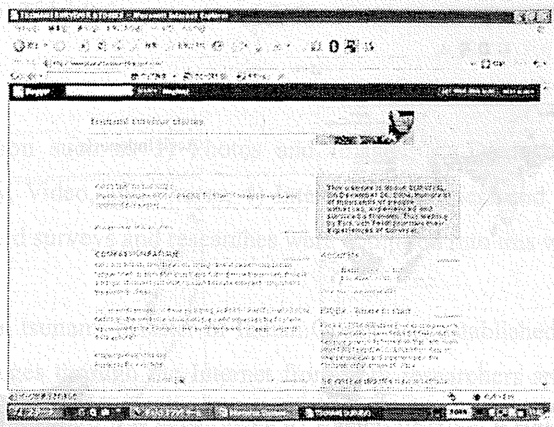


Fig. 12 Ethnography of Tsunami Survivors (TSUNAMI SURVIVOR STORIES)

5) Web Article

This category includes news article database collected by Okano of National Museum of Ethnology, and Abe of Tohoku University. The entire news article was categorized according to area or country, date, and contents. Contents are categorized following eight topics; 1) tsunami, 2) damage, 3) earthquake, 4) human response, 5) disaster response, 6) historic tsunami, 7) international assistance, and 8) recovery and reconstruction.

7.10. Links with relating website

This category is URL links with several portal sites on this disaster.

7.11. Comments

Contents of this web site still have been updated continuously. Useful Information and data sets has been contained in this web site. Further development of this web site to be real portal site to be tsunami research and awareness rising on tsunami disaster should be considered.

Acknowledgement

This web site has been managed through contribution from many people and organizations. We really appreciate those who admit to link web sites which include precious data and information, and admit to store precious data set and information into this web site.